2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #32972

Elementary Teachers' Verbal Support of Engineering Integration in an Interdisciplinary Project (Fundamental, Diversity)

Miss Sarah Catherine Lilly, University of Virginia

Sarah Lilly is a PhD student in the Department of Curriculum, Instruction and Special Education at the University of Virginia. She holds a B.S. in Mathematics and English and an M.A.Ed. in Secondary Education from The College of William and Mary. Her research centers on STEM education, particularly using qualitative methods to understand the integration of math and science concepts with computational modeling and engineering design practices in technology-enhanced learning environments. Prior to beginning doctoral work, she taught secondary mathematics for four years as well as created and implemented an interdisciplinary, project-based mathematics, science, and principles-of-technology curriculum for freshmen and sophomore high school students in Albemarle County, Virginia.

Ms. Anne Marguerite McAlister, University of Virginia

Anne M. McAlister is a PhD student and graduate research assistant in the Department of Curriculum and Instruction and Special Education at the School of Education and Human Development at the University of Virginia. Her research focuses on identity development in higher education, and how STEM graduate students balance and prioritize multiple identities. Before beginning doctoral work, she earned her BS in Chemical Engineering from The Ohio State University.

Prof. Jennifer L. Chiu, University of Virginia

Jennifer Chiu is an Associate Professor of STEM Education at the University of Virginia School of Education and Human Development. She holds a B.S. in Engineering (Product Design) from Stanford University and an M.A. and Ph.D. in Science Education from UC Berkeley. She researches how to support K-12 students, teachers, and preservice teachers across science, engineering, mathematics, and computer science disciplines as well as how to support STEM in informal learning contexts. Before becoming a professor, she worked as an engineer at Hewlett Packard and taught high school mathematics and science in California and Oklahoma.

Elementary Teachers' Verbal Support of Engineering Integration in an Interdisciplinary Project (Fundamental, Diversity)

Abstract

Despite national emphasis on authentic science, technology, engineering, mathematics, and computer science (STEM+CS) projects in classrooms, research continues to demonstrate opportunity gaps in learning STEM+CS for students with disabilities. This study investigates how teachers verbally support students in two differently tracked classrooms to engage in engineering lessons that integrate science and computer science. Specifically, this study explores how the same elementary teachers both implicitly and explicitly support students across two classroom contexts, one class section with a larger proportion of students who were tracked into accelerated mathematics and another class section with a larger proportion of students with individualized educational plans (IEPs). Transcripts of whole-class discussion were analyzed for interdisciplinary instructional moves in which teachers verbally supported the integration of disciplines to help students to engage in interdisciplinary activities. Findings reveal that all of the interdisciplinary instructional moves were implicit for the class section with a large proportion of students in advanced mathematics while most were explicit for the class section with students with IEPs, and that most of the interdisciplinary instructional moves were added by the teachers rather than planned in the curriculum materials. Most commonly, teachers added interdisciplinary instructional moves between computer science and engineering. Implications of this study include recommendations for support that teachers need to engage in the important, but challenging, work of integrating science and computer science practices through engineering lessons within elementary science classrooms. This study adds to a growing understanding of equitable learning opportunities in interdisciplinary learning through engineering for elementary students.

Introduction

Recent research has focused on understanding how teachers support precollege students' engagement in engineering practices (Watkins et al., 2018) and the benefits of integrating engineering and engineering design in precollege classes, including improved achievement in science, ability to engage in science and engineering practices, and increased awareness of engineering (National Academy of Engineering and the National Research Council; Katehi et al., 2009). Further, there is a national emphasis on integrating engineering, science, and computer science practices and concepts in science classrooms (NGSS Lead States, 2013) through interdisciplinary curricula. However, there is not a single, agreed upon definition of what counts as interdisciplinary at the elementary level (e.g., Breiner et al. 2012; Estapa et al., 2017; Roehrig et al. 2012; National Research Council (NRC), 2014). Instead there are many commonly accepted models of interdisciplinary STEM+CS (Johnson et al., 2020) that are context-dependent (Bybee, 2013) or dependent on the stakeholders involved in the integration (Breiner et al., 2012). In this study, we define interdisciplinary curricula as curricula that interweaves practices and concepts from multiple disciplines through building connections between these different disciplines and real-world problems within a single classroom environment (Stohlmann et al., 2012).

Previous research on interdisciplinary curricula has explored the integration of science, technology, engineering, mathematics, and computer science (STEM+CS) disciplines and underscored the importance of incorporating real-world problems (Johnson et al., 2020), engaging in practices and solving problems similar to disciplinary professionals (e.g., Barth et al., 2017), making STEM+CS meaningful to students (i.e., Guzey et al., 2016), and offering connections between school contexts and possible STEM+CS careers (i.e., Roehrig et al., 2012). However, very few studies investigate how these STEM+CS concepts and practices are enacted in inclusive classrooms with students with identified disabilities or individualized educational plans (IEPs). Students with disabilities are often ignored in STEM+CS education research (e.g., Villanueva et al., 2012), and science contexts are often understudied in special education research (e.g., Therrien et al., 2011). Research also documents disparities among K-12 STEM+CS experiences for students with disabilities, with students with disabilities having less opportunities and access to STEM+CS content and courses (U.S. Department of Education, 2014, 2018) as well as how inquiry- or project-based learning can be somewhat at odds with effective teaching practices for students with disabilities (Therrien et al., 2017). Thus, it is imperative to understand how to support students with disabilities within inclusive classrooms to engage in integrated STEM+CS, including engineering lessons that integrate science and computational practices. Further, research must also consider how teachers support students to recognize their ability to engage in STEM+CS practices in their current lives as well as, possibly, in their future careers (Roehrig et al., 2012).

This study investigates how elementary teachers verbally support students in two differently tracked classrooms to engage in science and computational practices during engineering lessons. In these engineering lessons, students investigated the world around them (science) and applied scientific ideas to develop solutions (engineering) using computational modeling to test and optimize their designs (computer science). The purpose of this study is to capture how teachers provide support for students to integrate scientific and computational practices in engineering lessons to provide insight into how to support all students to equitably engage in interdisciplinary STEM+CS instruction. Specifically, this paper addresses the following research questions: (1) In what ways do elementary teachers verbally support the integration of science and computer science into engineering lessons and to what extent are these supports planned in curricular materials or added in-the-moment? (2) To what extent do teachers' verbal supports for integration differ between two different classroom contexts?

Background

Engineering in elementary classrooms

National frameworks call for K-12 students to engage in engineering projects that integrate science, mathematics, and computer science (American Society for Engineering Education (ASEE), 2020; NRC, 2011). In the elementary grades, this includes integrating engineering concepts and practices into science classrooms where students define problems, use mathematics and computational thinking, and develop solutions while coming to understand engineering problems as constrained by materials and specified criteria, how testing and communication is integral to design, and the importance of optimization to find the best solution

(NGSS Lead States, 2013). Through these processes, students can use mathematics and computational thinking to model solutions or to analyze and interpret data.

In these kinds of engineering projects, teachers are expected to integrate disciplines and practices of science, engineering, and computer science in their instruction. Yet, little research has considered how teachers implement interdisciplinary curricula that integrates engineering, science, and computer science together within one classroom, particularly elementary teachers who often have little prior experience in teaching engineering or computer science and may need support to integrate engineering design with computational thinking into elementary science classroom settings (Purzer et al., 2014). For example, research has examined how to support elementary students to engage in science and engineering (e.g., Watkins et al., 2018), and science and computer science (e.g., Ketelhut et al., 2020), but not science, engineering, and computer science together.

Importantly, elementary teachers are also challenged with implementing these engineering projects into inclusive classrooms, which typically involve students with disabilities, a special education (SPED) teacher, a general education teacher, and students without disabilities. SPED teachers teach multiple content areas and provide complex support to students, but often have limited STEM+CS preparation (e.g., Taylor & Villanueva, 2017). Similarly, general education teachers often need support to provide opportunities for students with disabilities to engage in STEM+CS instruction (e.g., Cook et al., 2009). For example, research demonstrates that students with disabilities may need more explicit support in order to engage with inquiry-based projects (e.g., Therrien et al., 2017) and similarly engage with science, computer science, and engineering practices. However, explicit support does not necessarily mean that instruction is not student-centered and open-ended, but instead that expectations, behaviors, and processes are explicitly articulated and discussed (Therrien et al., 2017). Despite the importance of supporting all students to succeed in STEM+CS classrooms, very little research, if any, investigates how elementary teachers can support students to engage in engineering projects in inclusive settings.

Curriculum materials can help teachers work to enact engineering projects in their classrooms, particularly for elementary levels (Carlson et al., 2014). However, curricular materials alone are not enough to ensure equitable student engagement and opportunities with interdisciplinary curricula (e.g., Crotty et al., 2017) as teachers' instructional decisions can affect how and what kinds of practices or activities are used in the classroom (e.g., Remillard, 1999). More research is needed to understand exactly how elementary science teachers enact engineering projects that integrate science and computer science, particularly within inclusive classrooms. Thus, this paper focuses on the kinds of interdisciplinary verbal supports that elementary teachers provide students with during enactment of engineering lessons within a NGSS-aligned unit that integrates engineering, science, and computer science. In particular, we were interested in the kinds of instructional moves that teachers made in-the-moment that did and did not align with the planned curricular materials.

Teachers' instructional decision making

To examine the kinds of supports that teachers use during instruction, we adapted the Gess-Newsome (2015) instructional decision-making model that synthesizes other existing models of teacher professional knowledge (e.g., Ball et al., 2008; Grossman, 1990; Marks, 1990) as it articulates relationships among professional knowledge and teachers' classroom practice. In particular, this framework helps articulate the ways that teachers' topic-specific pedagogical knowledge (TSPK), amplifiers and filters (i.e., teacher beliefs and prior knowledge), and teachers' personal pedagogical content knowledge and skill (PCK&S) may influence enactment of interdisciplinary engineering curricula in elementary classrooms.

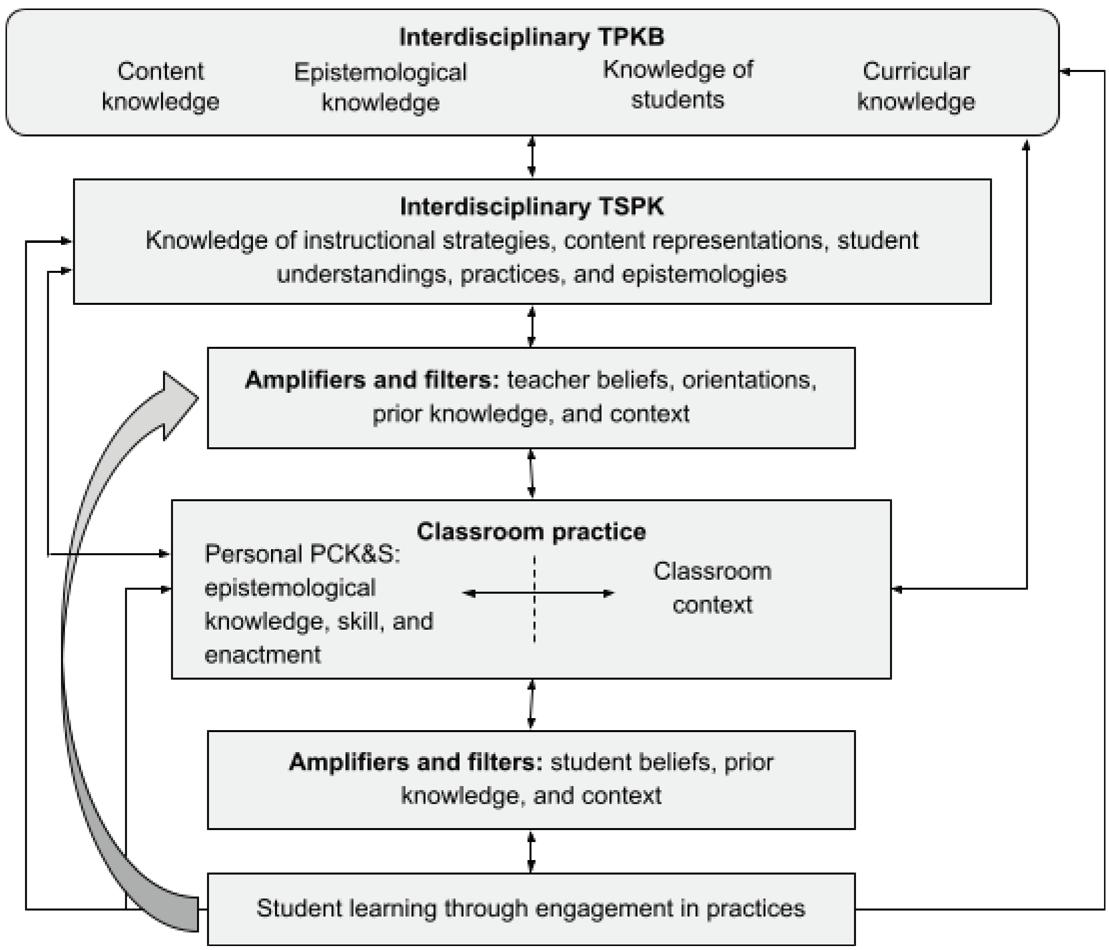

Figure 1. Adapted Gess-Newsome (2015) framework used in this study.

In particular, this study uses the lens of *topic-specific professional knowledge* (TSPK) to understand how teachers use curricular materials to shape engineering instruction. TSPK involves knowing ways in which to organize and represent content, including how to integrate content, practices, and habits of mind within lessons. TSPK also involves knowledge of appropriate instructional strategies, including knowledge of potential alternative student ideas with students at a particular grade band. For example, for teachers to support modeling across disciplines of science, engineering, and computer science, teachers need to understand modeling concepts and practices in each of these disciplines and need to be able to make connections and distinctions among and between disciplines for a specific grade band. Although seemingly similar to pedagogical content knowledge (PCK; e.g., Shulman, 1986), TSPK is conceptualized as outside of individual teachers' minds and instead is codified by experts for use and study by teachers in educative curricular materials or other professional learning opportunities.

While professional learning experiences can outline goals for interdisciplinary-specific TSPK, it may not be feasible for teachers to have access to professional learning opportunities that would address TSPK for all relevant disciplines within an interdisciplinary project. To provide additional support, curriculum designers can include explicit curricular materials (i.e., a teacher's guide or instructional slides) to provide additional interdisciplinary-specific TSPK.

Teachers' TSPK passes through their amplifiers and filters (Figure 1) that in turn affect their instructional decisions in classrooms. Teachers' amplifiers and filters include the beliefs and orientations of teachers. Teachers' beliefs include their own ways of thinking and attitudes about teaching, the disciplines that they teach, and the students that they teach (Muijs & Reynolds, 2002). For example, some teachers may hold different beliefs about what interdisciplinary means, their own ability to implement interdisciplinary curricula, or the ability of students with disabilities to engage in interdisciplinary practices.

Through these amplifiers and filters, teachers have agency to choose how they accept, modify, and/or reject curricular materials and implement professional knowledge in their own classrooms (e.g., Remillard, 2005). Specifically, since engineering concepts and practices are often unfamiliar to elementary teachers, the beliefs of elementary teachers towards engineering can particularly affect the ways in which they integrate engineering practices (Lachapelle et al., 2014). For example, a teacher may allocate less time for engineering activities within an interdisciplinary project than is recommended by curricular materials due to doubts about their own ability to teach engineering content. Or a teacher may provide different kinds of verbal support for students to engage with certain engineering practices based on their perceptions of students' abilities to engage in engineering practices in different classroom contexts (Lilly et al., 2020). Teachers' beliefs can then affect the effectiveness of teachers' implementation of interdisciplinary curricula and the opportunities that students have to engage in certain interdisciplinary practices (Askew et al., 1997).

In classroom practice, teachers draw upon their own privately-held PCK&S to make both planned and in-the-moment instructional moves. PCK&S is a kind of *reflection in action* (Schön, 1983) where teachers monitor student involvement to make instructional changes based on what they notice in their classrooms while enacting planned instruction (Gess-Newsome, 2015). Thus, instructional moves are based upon specific classroom contexts for specific content and learners. For example, a teacher in a classroom with a high percentage of students with disabilities could make an in-the-moment decision to use direct instruction directed towards the whole class as a way to explain the engineering design process rather than having students explore the process individually based on their noticing of student engagement.

Integrating engineering design, particularly, in interdisciplinary elementary projects can be challenging for teachers, as students' ideas for how to solve problems as well as the questions that students ask can be unpredictable. Without interdisciplinary-specific PCK&S, it may be difficult for teachers to respond to students' engineering solutions and questions (Johnson et al., 2017) through in-the-moment decisions. Additionally, elementary teachers may struggle to evaluate the ways in which their students' engineering designs meet specifications and constraints if they are not knowledgeable about engineering analysis (Brophy et al., 2008) and focus on logistics instead of engineering content and practices during classroom instruction (Diefes-Dux, 2004). For elementary teachers integrating engineering-specific concepts and practices, investigating PCK&S may be particularly important to help these teachers draw on their experiences and skills in other disciplines and use these skills to enact interdisciplinary projects.

Thus, in this study, we focus on teachers' instantiated PCK&S by exploring how teachers provide verbal support to integrate scientific and computational practices into engineering lessons during classroom implementations. In particular, we seek to capture how teachers used both *planned* instructional moves that were provided in the curricular educative supports and professional development (TSPK), as well as *added* instructional moves used outside of the TSPK and educative materials in response to their students or classroom context. Additionally, we aim to capture if classroom contexts with different percentages of students with disabilities may influence the kinds of instructional moves that teachers exhibit and use. By investigating how teachers enacted a planned engineering curricular unit across two different classroom settings, we aim to highlight the kinds of support that teachers may need to engage in the important, challenging work of integrating science and computer science practices through engineering lessons within elementary science classrooms for all students.

Methods

Settings and participants

This study took place in a public elementary school with students classified as: 38% Black, 13% Hispanic, 38% White, 6% Asian, and 5% Multiple Races, with 18% of students with Disabilities, 17% Emerging Bilinguals, and 53% qualified for free or reduced-price lunch. Participants include two elementary teachers, Ms. Lee and Mr. Vista, both of whom have an undergraduate degree in a science discipline. Ms. Lee is a fifth grade math and science classroom teacher, and Mr. Vista is the STEM coordinator for the elementary school. These teachers co-led two fifth grade classes where students were tracked based on mathematics achievement, resulting in one class (Orange Class) having a larger proportion of students in accelerated mathematics, and another class (Blue Class) having a larger proportion of students with IEPs and accommodative placement within a collaborative classroom. On occasion, there was a SPED teacher who was present in the Blue Class. However, the SPED teacher did not lead or contribute to whole-class discussion during the engineering lessons but played a support role to provide targeted help for students with disabilities within the classroom. Thus, the SPED teacher's verbal support is not considered in this study focused on whole-class discussion.

Curriculum

The four-week interdisciplinary project challenged students to integrate engineering, science, and computer science to design a way to reduce water runoff on their school grounds (Chiu et al., 2019). To do this, students needed to consider parking requirements, setting aside space for a grassy field, and providing accessible play areas for students with physical disabilities, with budget constraints and specifications for water runoff amounts with rainfall events. Students engaged in defining the water runoff problem at their school, investigated underlying science concepts through hands-on investigations with different surface materials, generated design solutions, created a computational model to test their design solutions, and tested and evaluated multiple design solutions before presenting their designs to the school principal. There were ten total lessons in the project, and the two of those that focused on engineering were selected to be examined in this study. In these engineering lessons, curricular materials called for integrating engineering, science, and computer science through activities in which students generated engineering designs that build upon their understanding of water runoff and testing their engineering designs with their computational model. Specifically, the first of these engineering lessons was focused on generating solutions and had students create design solutions to minimize water runoff and meet project criteria within one class period. The second engineering lesson focused on generating and comparing solutions and had students develop additional solutions and test them using the computational model over two class periods.

Data sources

Whole-class discussion, led by Mr. Vista and Ms. Lee, was captured by audio recording devices placed throughout the classroom. The audio of whole-class discussions was then transcribed and used for analysis. The Teacher's Guide for the project, which contained both the student activities as well as interdisciplinary-specific TSPK through pedagogical strategies and educative support for teachers, was used to determine if verbal supports of student engagement in interdisciplinary activities were planned within the curricular materials.

Analysis

We operationalized interdisciplinary PCK&S as instructional moves in which teachers provided verbal support for students to integrate scientific or computational concepts or practices into the engineering lessons. Two researchers read through all transcripts of both class sections and identified instructional moves in whole-class discussion in which teachers verbally supported students to use scientific or computational concepts or practices to solve the engineering problem. An instructional move began when a teacher offered verbal support of the integration of specific disciplines and ended when the topic of the whole-class discussion either moved away from verbally supporting the integration of disciplines or the whole-class discussion ended as students began or continued their work in small groups. This meant that instructional moves could include multiple turns of talk in the form of verbal support from both teachers as well as interjections and questions from students.

The list of instructional moves was compiled, and each example was assigned a label of the class section (O for Orange Class and B for Blue Class) and a number (according to when the instructional move occurred chronologically in the engineering lessons). For example, O.1 was the first interdisciplinary instructional move that occurred in the engineering lessons for the Orange Class.

To identify the ways in which elementary teachers verbally support the integration of science and computer science into engineering lessons, we created an analytic framework that places planned versus added support on one axis and explicit versus implicit support on the other axis, leading to four differentiated quadrants of support (Figure 2). Planned interdisciplinary instructional moves are those which were documented in the curricular materials and provided to the teachers (TSPK). Added interdisciplinary instructional moves, on the other hand, were moves that were not documented in the curricular materials. Implicit support for integration involved instructional moves that helped students engage in practices without explicit articulation for how or why they were doing so. In contrast, explicit use of integration included teachers' instructional moves that helped students to know how and why they were integrating disciplines in their practice.

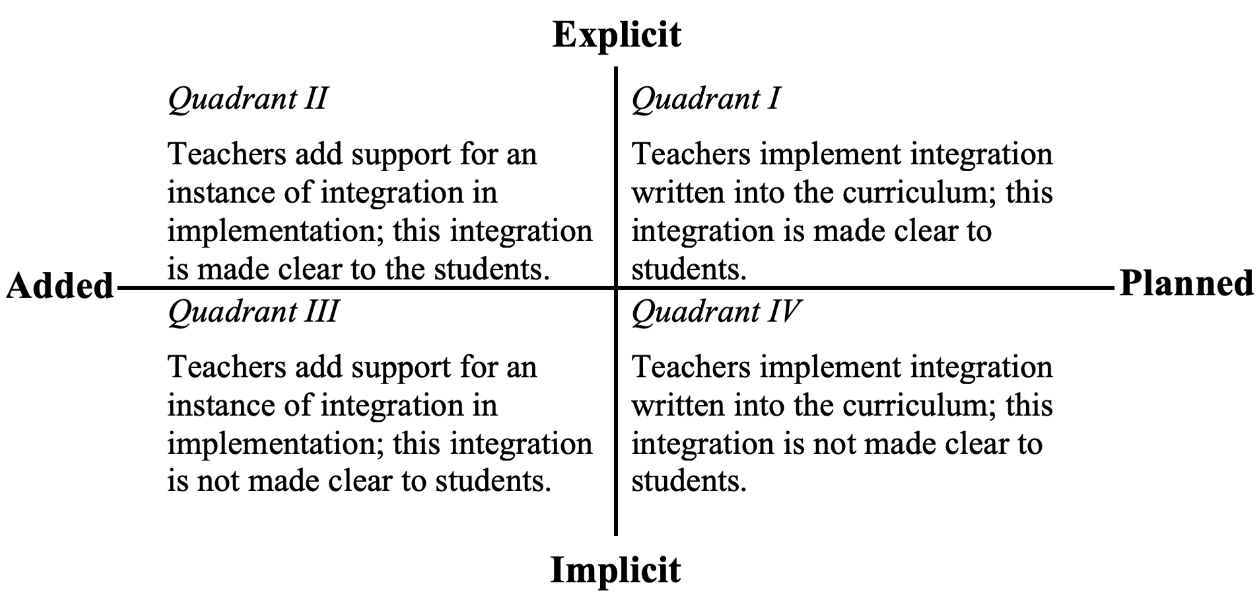

Figure 2. Quadrants of Support Based on the Added-Planned and Explicit-Implicit Axes.

Two researchers then engaged in team coding, going through each individual interdisciplinary instructional move together and treating each individual interdisciplinary instructional move as a case (Miles et al., 2020). For first level codes, researchers discussed the integration that was happening and coded each case for whether it was made *explicit* to students and whether it was *planned* in the curricular materials. In order to determine if an interdisciplinary instructional move was planned, the researchers referred back to the Teacher's Guide to identify corresponding educative curricular materials. For each interdisciplinary instructional move, the researchers also identified and coded which disciplines were being integrated and noted the chronological order of the instructional move. The researchers created a visualization to graph each interdisciplinary instructional move based on its codes within the axes of explicit vs. implicit and planned vs. added (Figure 3). After discussing each interdisciplinary instructional move, the two researchers wrote a memo describing the interdisciplinary instructional move and the discussion about that move. Researchers then grouped memos based on quadrants and used the second cycle method of pattern coding to look across cases for emerging themes represented in groups of instructional moves (Miles et al., 2020). These themes are shared below.

Findings

We focus on whether interdisciplinary instructional moves were made explicitly evident to students as well as whether the interdisciplinary instructional moves were planned or added. In Figure 3, the type of disciplinary integration (i.e., computer science and engineering or science and computer science and engineering) is indicated by a shape. As we discuss the figure, we note quadrants as Quadrant I, Quadrant II, Quadrant III, and Quadrant IV starting in the upper right corner and moving counterclockwise.

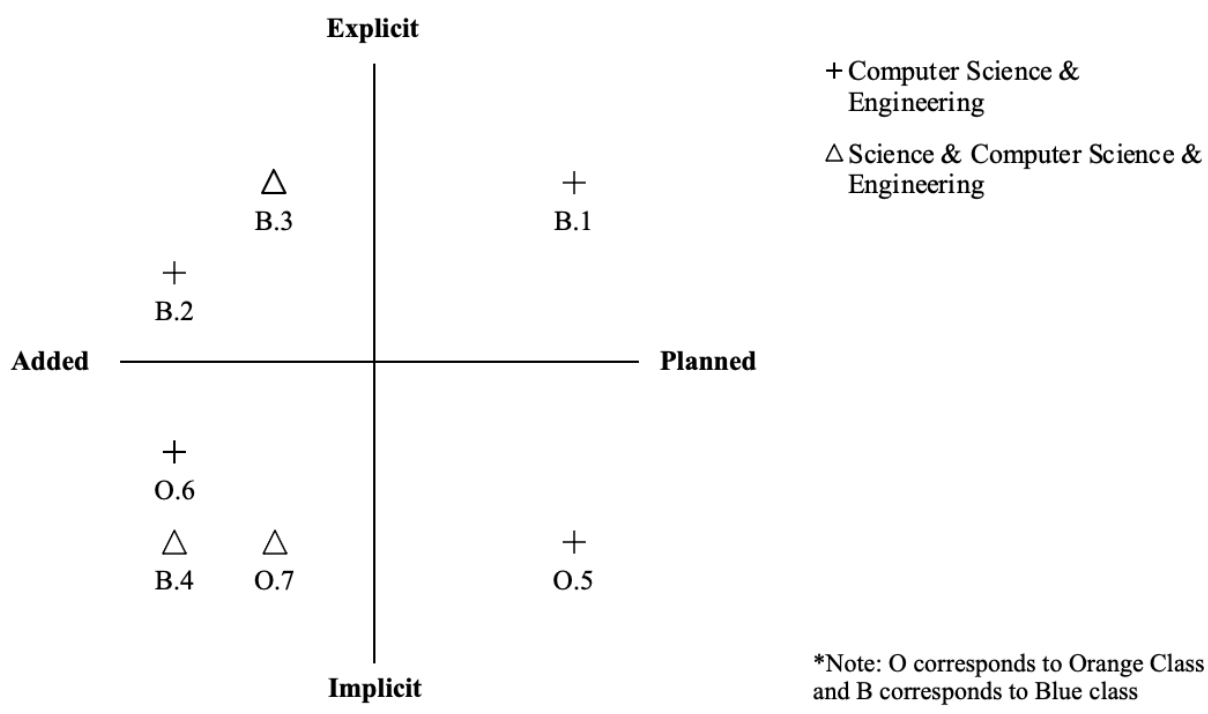

Figure 3. Interdisciplinary Instructional Moves by Disciplinary Integration.

RQ1: In what ways do elementary teachers verbally support the integration of science and computer science into engineering lessons and to what extent are these supports planned in curricular materials or added in-the-moment?

Considering the horizontal axis, most of the interdisciplinary instructional moves are added rather than planned (Figure 3; 5:2) meaning that most of the interdisciplinary instructional moves were added by the teachers rather than planned in the Teacher's Guide. Considering the vertical axis, the interdisciplinary instructional moves were more closely split between explicit and implicit (Figure 3; 3:4). In combination, the added interdisciplinary instructional moves were split (2:3) between explicit and implicit (Figure 3; Quadrants II and III, respectfully). The planned interdisciplinary instructional moves were also split evenly (1:1) between explicit and implicit (Figure 3; Quadrants I and IV). Considering the discipline(s), there was more support of computer science integration with engineering (five interdisciplinary instructional moves) than science and computer science with engineering (two interdisciplinary instructional moves) and no interdisciplinary instructional moves of only science integration with engineering (Figure 3). While the interdisciplinary instructional moves of computer science and engineering were distributed across the quadrants, the interdisciplinary instructional moves of science, computer science, and engineering were added by the teachers.

Planned support. As the Teacher's Guide for the engineering lessons planned for students to use computer models to test their engineering designs, the majority of interdisciplinary instructional moves were teachers verbally supporting the integration of computer science with engineering (Figure 3). Two of these interdisciplinary instructional moves were planned by the Teacher's Guide. For example, before students began to test their engineering designs, the teachers made explicit to the students that they are using computer science to test their engineering designs based on the problem definition and constraints given initially (B.1). To do this, Mr. Vista "remind[ed] everyone of their original [design] that they developed" and helped students connect to their previous work, "yesterday was trying to learn how to code a computer model that will test these designs to see how much runoff, how much absorption, and basically how good your model is based on what [principal] wanted us to do" as suggested by the Teacher's Guide. The discussion continued with Mr. Vista explaining to the students that computer science is being used to support the engineering of their design as they are making changes after using the computer model to evaluate if the project constraints are being met. This support helped to explain the ways in which the disciplines are being integrated within the activity.

The other planned interdisciplinary instructional move occurred when Mr. Vista supported students in the Orange Class to create multiple engineering designs within the design constraints so that they would have multiple designs to test using the computer model (O.5). His support was procedural, "You have to create two more designs and then we're actually going to test all three and see how they compare to each other." This support was implicit as students were supported to test multiple engineering designs with their computer model but were not supported to further understand the ways in which using the computer model would help them to compare their designs based on outputs that correspond to the design constraints.

Added support. In addition to these planned interdisciplinary instructional moves, the teachers added more support for both the integration of computer science and engineering as well as for the integration of science and computer science and engineering than was planned by the Teacher's Guide. For example, as students tested their engineering designs using the computational model, the Teacher's Guide suggested that teachers support students to keep track of specific values as they tested each design. In the class sections, teachers went beyond suggestions in the Teacher's Guide by also verbally supporting students to understand that they were tracking specific values as a way to capture their work for a unit-end presentation. For example, in the Blue Class, Mr. Vista offered added support for how testing the computational model could help students prepare for the science practice of communication in creating presentations (B.4), saying,

> So [principal] is going to be making decisions based on what you guys have, right? So what I want you to do right now is continue to test your designs, make sure that you've written down the following information on page 26 and 27 once you've finished with your designs, the cost and the runoff, and then what's below each square … Make sure you filled out this information below the design so that you can remember this for later on in case you want to do a different design.

By reminding students that the principal will be deciding on the best design based on how students' designs take into account project constraints, the teachers made it clear that students needed to discuss this in their presentations.

Similarly, in the Orange Class, the teachers additionally explained to the students how and why the output information from testing their engineering designs with their computational model was important for their unit-end presentations (O.7). Ms. Lee said,

> You need to make sure that you put how much it costs and what the runoff amount was over that design. So that when you guys are giving your presentations, you could explain what caused runoff and why you decided to change from that design, because we need to know. Tomorrow, not only are you going to be presenting your final, but you need to explain why you decided to go with that design.

In both class sections, this support helped students to integrate science and engineering and computer science into their presentations.

However, this integration was not made explicitly clear to students in either class section. Students could have been supported to explicitly understand that the data could show how the students were using the concepts from science to evaluate the computational models of their engineering design and to communicate how these evaluations helped them to choose their final designs. This would have moved the verbal support from implicitly helping students to engage in an interdisciplinary activity to explicitly understanding the connections between the disciplines within the activity.

RQ2: To what extent do teachers' verbal supports for integration differ between different classroom contexts?

The verbal support for intertegration differed between the two class sections in that all of the interdisciplinary instructional moves were implicit for the Orange Class, with more students in advanced mathematics, while most were explicit for the Blue Class, with more students with IEPs (Figure 3). Sometimes this difference in support could be seen in direct comparison between the two class sections as students were supported differently to engage in the same activity. For example, Ms. Lee offered added support in the Orange Class (O.6) to help students use their computational model to test their engineering designs, either in iterations of the same design or different designs: "So if you press this, it's going to take away your whole design. If you want to run the same tests on the same design, you press this. But if you want to start completely over, ok". Similar support was offered in the Blue Class. However, this support made the integration between the computer science and engineering disciplines explicit to students (B.2) as they received information about why it is important for students and engineers to test iterations of the same design or different designs. Mr. Vista started by telling the students, "Here's the great thing. If you don't like your design, you can change it". The discussion continued to include an explanation of how computer science can help engineers to engage in an iterative process of designing, testing, and changing an engineering design. Thus, instead of only supporting students in the process of using computer models to test their engineering design as was done in the Orange Class, Mr. Vista prepared students to understand how they were engaging in practices authentic to engineers and the importance of computer science in doing so. This support was not planned by the curricular materials, and rather was added by Mr. Vista for the context of the Blue Class.

Other times, explicit support was added specifically for the Blue Class with no similar, but implicit, support occurring for the Orange Class. For example, the teachers recognized that students in the Blue Class needed additional support to troubleshoot their computer program and consider illogical outcomes while testing an engineering design (B.3). In this case, Mr. Vista said, "It's not really possible to have negative runoff when you're talking about like a real situation". This connection continued as the teachers encouraged the students to integrate the knowledge they had from their science investigations to evaluate if the results of the computer model of their engineering design were logical or not in a real context. They explicitly told students that it was important to use science evidence in conjunction with computer science data when evaluating computer models. In doing so, the teachers supported students in the Blue Class to think about the science concepts that they learned as they used computer science to model their engineering design and, thus, encouraged students to integrate all three of these disciplines in their thinking. Teachers did not make this connection, explicitly or implicitly, in the Orange Class.

Discussion and implications

This study investigated the kinds of verbal supports teachers used to help students engage in the engineering lessons of an interdisciplinary project in two elementary classrooms. We found that teachers both enacted planned instructional moves and added their own instructional moves to tailor the curriculum to the specific classroom contexts. Specifically, teachers enacted more added interdisciplinary instructional moves than interdisciplinary instructional moves that were planned in the Teacher's Guide. Understandably, these teachers brought their insights and experiences to the project implementation and made in-the-moment customizations of the curricular materials based upon their demonstrated interdisciplinary PCK&S and the classroom context. These findings highlight the need for further research into the kinds of interdisciplinary instructional moves that teachers may add to instruction to provide crucial insight into revisions of educative materials and enactment of engineering projects. Further, results highlight the need for more research into the reasons and justifications that teachers give for their instructional decisions. For example, reflections or replay interviews of teachers (Radloff & Guzey, 2017) may provide crucial insight to understand the teachers' perceptions of teaching interdisciplinary curricula and the responsive decisions that they made while engaging in this challenging work.

Findings revealed that the teachers provided more explicit support to the Blue Class than to the Orange Class, which may be a result of the teachers' beliefs about the ability of certain students to engage in interdisciplinary practices within engineering lessons. For example, there was a higher percentage of students with IEPs in the Blue Class, therefore the teachers may have drawn on their beliefs that those students needed more explicit support or their PCK&S around making ideas explicit to students with IEPs, drawing on effective practices in SPED (Therrien et al., 2017). Although teachers necessarily adjust and customize curricular materials to specific learning contexts, results highlight the potential of unintended outcomes that may arise as a result of customization. Students in different class sections received different kinds of verbal support that may or may not have a positive impact on students. For example, explicit support that provides the reasoning and purposes behind experiences may be beneficial to all students. On the other hand, providing explicit support for students too often may change the academic rigor of the activities or sway discussions to become more teacher-centered. Future work should explore how these kinds of instructional moves may relate to students' learning experiences.

In classroom practice, the teachers used interdisciplinary-specific and general PCK&S to make in-the-moment instructional moves drawing upon their knowledge of the learners within their classroom. They did this by generally adding what they thought their students would need through added support as well as in making support explicit for students in the Blue Class. We note that, as elementary teachers who have undergraduate degrees in a science discipline, the teachers in this study are atypical in elementary settings. Other elementary teachers may have knowledge about such instructional strategies but not have the skill to implement the strategies in practice. To help such teachers enact integrated STEM+CS projects through engineering in classrooms, it is important for teachers to be provided with the support and time to delve into interdisciplinary curricula materials as well as to learn about instructional models and existing national models for interdisciplinary projects (i.e., ASEE, 2020; NGSS Lead States, 2013).

Limitations

Limitations to this study include that the primary data source was transcripts of whole-class discussion. There may have been other supports for integration in small group discussion that were not observed by this study. Another limitation that arises from analyzing whole-class discussion is not having information about how and why teachers enacted the verbal supports or how teachers' supports may have influenced students' learning experiences. In addition, this study only analyzed two engineering-focused lessons. Further research could explore class sections across lessons that focus on different disciplines (i.e., computer science-focused and science-focused lessons in addition to the engineering-focused lessons) to investigate the extent to which findings may generalize across lessons.

Conclusion

This paper highlights examples of how teachers supported students to integrate scientific and computational practices into engineering lessons in two differently-tracked class sections. Supporting students' integration of practices within interdisciplinary projects is challenging and important work (Stohlmann et al., 2012), particularly as teachers were tasked with implementing this curriculum in different classroom contexts. Results highlight the kind of instructional moves that teachers use to implement interdisciplinary engineering instruction above and beyond educative curricular materials and demonstrate how classroom context can influence the kind of instructional supports that teachers may choose to enact to support specific student needs. Findings underscore the need for more research to better understand what kinds of support teachers need to be able to integrate engineering, science, and computer science content and practices within their elementary classrooms and provide equitable learning opportunities for all students.

References

American Society for Engineering Education (2020). Framework for P-12 Engineering Learning. Downloaded from https://p12framework.asee.org/

Askew, M., Brown, M., Rhodes, V., Wiliam, D., & Johnson, D. (1997). Effective Teachers of Numeracy in Primary Schools: Teachers' Beliefs, Practices and Pupils' Learning.

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special. *Journal of teacher education*, *59*(5), 389-407.

Barth, K., Bahr, D., & Shumway, S. (2017). Generating clean water. *Science and Children*, *55*(4), 32-38.

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*(1), 3-11.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P‐12 classrooms. *Journal of Engineering Education*, *97*(3), 369-387.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. NSTA press.

Carlson, J., Davis, E. A., & Buxton, C. (2014). Supporting the implementation of the Next Generation Science Standards (NGSS) through research: Curriculum materials. *Retrieved November*, *18*, 2016.

Chiu, J. L., McElhaney, K., Zhang, N., Biswas, G., Fried, R., Basu, S., & Alozie, N. (2019, April). A Principled Approach to NGSS-Aligned Curriculum Development: A Pilot Study. Paper presented at NARST Annual International Conference, Baltimore, MD.

Cook, B. G., Tankersley, M., & Landrum, T. J. (2009). Determining evidence-based practices in special education. *Exceptional children*, *75*(3), 365-383.

Crotty, E. A., Guzey, S. S., Roehrig, G. H., Glancy, A. W., Ring-Whalen, E. A., & Moore, T. J. (2017). Approaches to integrating engineering in STEM units and student achievement gains. *Journal of Pre-College Engineering Education Research (J-PEER)*, *7*(2), 1.

Diefes-Dux, H. A., Moore, T., Zawojewski, J., Imbrie, P. K., & Follman, D. (2004, October). A framework for posing open-ended engineering problems: Model-eliciting activities. In *34th Annual Frontiers in Education, 2004. FIE 2004.* (pp. F1A-3). IEEE.

Estapa, A. T., & Tank, K. M. (2017). Supporting integrated STEM in the elementary classroom: a professional development approach centered on an engineering design challenge. *International Journal of STEM education*, *4*(1), 6.

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK. *Re-examining pedagogical content knowledge in science education*, *41*(7), 28-42.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. Teachers College Press, Teachers College, Columbia University.

Guzey, S. S., Moore, T. J., & Harwell, M. (2016). Building up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials. *Journal of Pre-College Engineering Education Research (J-PEER)*, *6*(1), 2.

Johnson, A. W., Wendell, K. B., & Watkins, J. (2017). Examining experienced teachers' noticing of and responses to students' engineering. *Journal of Pre-College Engineering Education Research (J-PEER)*, *7*(1), 2.

Johnson, C. C., Mohr-Schroeder, M. J., Moore, T. J., & English, L. D. (Eds.). (2020). *Handbook of research on STEM education*. Routledge.

Katehi, L., Pearson, G., & Feder, M. (Eds.). (2009).Engineering in K–12 education: Understanding the status and improving the prospects.Washington, DC: National Academies Press.

Ketelhut, D. J., Mills, K., Hestness, E., Cabrera, L., Plane, J., & McGinnis, J. R. (2020). Teacher change following a professional development experience in integrating computational thinking into elementary science. *Journal of science education and technology*, *29*(1), 174-188.

Lachapelle, C. P., Hertel, J. D., Shams, M. F., San Antonio, C., & Cunningham, C. (2014, January). The attitudes of elementary teachers towards elementary engineering (research to practice). In *121st ASEE Annual Conference and Exposition: 360 Degrees of Engineering Education*.

Lilly, S., McAlister, A. M., Fick, S. J., Chiu, J. L., & McElhaney, K. W. (2020, June), *Supporting Upper Elementary Students' Engineering Practices in an Integrated Science and Engineering Unit.* Paper presented at 2020 ASEE Virtual Annual Conference Content Access, Virtual Online. https://peer.asee.org/35258

Marks, R. (1990). Pedagogical content knowledge: From a mathematical case to a modified conception. *Journal of teacher education*, *41*(3), 3-11.
Miles, M.B., Huberman, A.M., & Saldana, J.M. (2020). *Qualitative data analysis: A methods sourcebook, 4th Edition*. Thousand Oaks, CA: SAGE.
Muijs, D., & Reynolds, D. (2002). Teachers' Beliefs and Behaviors: What Really Matters? *The Journal of Classroom Interaction, 37*(2), 3-15.
National Research Council. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. National Academies Press.
NGSS Lead States. (2013). Next generation science standards: For states, by states. Washington, DC: The National Academic Press.
Purzer, Ş., Strobel, J., & Cardella, M. E. (Eds.). (2014). *Engineering in pre-college settings: synthesizing research, policy, and practices*. Purdue University Press.
Radloff, J., & Guzey, S. (2017). Investigating changes in preservice teachers' conceptions of STEM education following video analysis and reflection. *School Science and Mathematics*, *117*(3-4), 158-167.
Remillard, J. T. (1999). Curriculum materials in mathematics education reform: A framework for examining teachers' curriculum development. Curriculum Inquiry, 29(3), 315-342.
Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of educational research*, *75*(2), 211-246.
Roehrig, G. H., Moore, T. J., Wang, H. H., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K‐12 engineering standards on the implementation of STEM integration. *School science and mathematics*, *112*(1), 31-44.
Schön, J. (1983). *Petrophysik: Physikalische eigenschaften von gesteinen und mineralen* (p. 405). Berlin: Akademie-Verlag.
Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational researcher*, *15*(2), 4-14.
Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research (J-PEER)*, *2*(1), 4.
Taylor, J. C., & Villanueva, M. G. (2017). Research in science education for students with special needs. In M. T. Hughes & E. Talbott (Eds.), The Wiley handbook of diversity in special education (pp. 231 - 252). John Wiley & Sons.
Therrien, W. J., Benson, S. K., Hughes, C. A., & Morris, J. R. (2017). Explicit instruction and Next Generation Science Standards aligned classrooms: A fit or a split?. *Learning Disabilities Research & Practice*, *32*(3), 149-154.
Therrien, W. J., Taylor, J. C., Hosp, J. L., Kaldenberg, E. R., & Gorsh, J. (2011). Science instruction for students with learning disabilities: A meta‐analysis. *Learning Disabilities Research & Practice*, *26*(4), 188-203.
U.S. Department of Education. (2018). 2015-2016 civil rights data collection: STEM course taking. U.S. Department of Education, Office of Civil Rights.
U.S. Department of Education, Office of Civil Rights. (2014). Civil rights data collection data snap-shot: College and career readiness.
Villanueva, M. G., Taylor, J., Therrien, W., & Hand, B. (2012). Science education for students with special needs. *Studies in Science Education*, *48*(2), 187-215.

Watkins, J., McCormick, M., Wendell, K. B., Spencer, K., Milto, E., Portsmore, M., & Hammer, D. (2018). Data‐based conjectures for supporting responsive teaching in engineering design with elementary teachers. *Science Education*, *102*(3), 548-570.