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A Professional Development Model to Integrate Computational Thinking Into Middle School Science Through Codesigned Storylines

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This article describes a professional development (PD) model, the CT-Integration Cycle, that supports teachers in learning to integrate computational thinking (CT) and computer science principles into their middle school science and STEM instruction. The PD model outlined here includes collaborative design (codesign; Voogt et al., 2015) of curricular units aligned with the Next Generation Science Standards (NGSS) that use programmable sensors. Specifically, teachers can develop or modify curricular materials to ensure a focus on coherent, student-driven instruction through the investigation of scientific phenomena that are relevant to students and integrate CT and sensor technology. Teachers can implement these storylines and collaboratively reflect on their instructional practices and student learning. Throughout this process, teachers may develop expertise in CT-integrated science instruction as they plan and use instructional practices aligned with the NGSS and foreground CT. This paper describes an examination of a group of five middle school teachers' experiences during one iteration of the CT-Integration Cycle, including their learning, planning, implementation, and reflection on a unit they codesigned. Throughout their participation in the PD, the teachers expanded their capacity to engage deeply with CT practices and thoughtfully facilitated a CT-integrated unit with their students.

Modern scientific inquiry increasingly depends on computation and computational tools to collect, analyze, and visualize streams of data and to develop models to explain phenomena and create solutions for problems (Foster, 2006). Yet, in many school districts the study of computing is often isolated in separate, elective classes, leading to inequities in opportunities to learn and engage in computational thinking skills (Margolis et al., 2008). Thus, districts in the United States are increasingly pushing to integrate computer science and computational thinking (CT) into mainstream science and integrated science, technology, engineering, and mathematics (STEM) classes that all students must take (Sengupta et al., 2013; Sherin et al., 1993).

Such an approach has several advantages: It ensures that diverse students have opportunities to learn CT, it reflects the changing practices of contemporary data-driven science, and it builds on the *Framework for K-12 Science Education* (National Research Council [NRC], 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013). CT is identified by the NGSS as one of the eight core Science and Engineering Practices (i.e., using mathematics and computational thinking; NRC, 2012; NGSS Lead States, 2013).

Programmable sensors that collect information such as temperature, humidity, noise level, and magnetism are becoming increasingly affordable and accessible to the mainstream population (Anastopoulou et al., 2012). These sensors present an opportunity for the integration of CT to move beyond large, prepopulated datasets that have traditionally been used to integrate computing concepts into science instruction. Supporting students to collect their own data grounds experiments in their lived experience and encourages students to ask questions such as “So what?” and “Why here?” (Buxton, 2010). However, science teachers are not often experts in supporting their students to use CT and programming to engage with the latest technology (Grover & Pea, 2013; Meerbaum-Salant et al., 2013).

Schoolwide Labs (https://www.colorado.edu/program/schoolwide-labs/), a National Science Foundation funded study, focused on strategies for integrating CT into middle school science in a way that complements and enhances students’ science learning. The project utilized a design-based implementation research approach (Fishman et al., 2013), in which new interventions are developed and refined through iterative design cycles that involve field deployment and data collection.

This project drew on the Computational Thinking for STEM Taxonomy developed by Weintrop et al. (2016) that highlights four sets of practices that are critical to scientific inquiry: data practices, computational modeling and simulation practices, computational problem-solving practices, and systems thinking practices. The language of the practices is intentionally aligned with the NGSS Science and Engineering Practices.

For science teachers to integrate computational activities productively into their instruction, they often need significant professional learning experiences and support (Goode et al., 2014; Grover & Pea, 2013). This article highlights a new professional learning model, referred to as the CT-

Integration Cycle (Gendreau Chakarov et al., 2019a). The CT-integration Cycle grounds teacher learning in actual teaching practices. It also supports teachers to learn about, plan for, and reflect on how they integrate CT with science instruction (Gendreau Chakarov, Biddy et al., 2019; Gendreau Chakarov, Recker et al. 2019; Gendreau Chakarov et al., in press). The CT-Integration Cycle provides a structure and process for teachers to become more knowledgeable about CT, programmable sensor technology, and their integration into NGSS-aligned science classrooms.

Research Questions

This article describes the exploration of one iteration of the CT-Integration Cycle that took place during the 2018-2019 school year. It highlights how this professional learning model played out in practice and addressed the following research questions:

1. How does the CT-Integration Cycle, including the related activities and tools, afford teachers opportunities to integrate CT and science?
2. In what ways do teachers experience and participate in the different phases of the CT-Integration Cycle?

Literature Review

Computational Thinking in Science

Scientists increasingly use computational tools and design processes (Foster, 2006). As the field increases in computational complexity, it has become more important to introduce computational tools and concepts into K-12 science classrooms. Introducing CT in K-12 science classrooms prepares students for careers as scientists (National Academy of Sciences, 2007), helps them see applications of computer science to other subject areas (Hambrusch et al., 2009; Lin et al., 2009), and can help students in their current and future lives regardless of whether they pursue a career in science (Hardy et al., 2020). Encouraging students to make connections between computer science and other fields, as well as having practical applications, has been suggested as a practice for broadening participation in the discipline (Barr & Stephenson, 2011; Ryoo et al., 2013; Scott et al., 2015).

Frequently, integrating CT into science classes revolves around students building and using simulations of computational models about a topic they are currently investigating and learning about (Blikstein, 2012; Sengupta et al., 2013; Tisue & Wilensky, 2004; Weintrop et al., 2016). While computational modeling and simulations provide many opportunities for CT integration, additional avenues of integration remain to be explored. Programmable sensor technology is becoming increasingly accessible and affordable for K-12 classrooms (Anastopoulou et al., 2012) and provides students an opportunity to collect their own large data sets and automate experimental setups. These tools can support computational modeling and other investigations that require collecting large data streams to understand scientific processes. These programmable sensor technology provide new and innovative ways to explore, understand, and experience the surrounding world (Hether et al., 2017).

Sensor technology can help make the invisible visible. Norooz et al. (2015) described the creation of an e-textile t-shirt, BodyVis (https://makeabilitylab.cs.washington.edu/project/BodyVis/), that displays the internal organs and physiological actions such as breathing and digesting. Equipped with biometric sensors and interactive visualization, BodyVis helps students understand the internal, unseen parts of the body by displaying heart rate, respiration, and digestion.

Additionally, sensors can allow for more than passive data collection. As part of the InSPECT project (https://concord.org/our-work/research-projects/inspect; Hardy et al., 2020) students used sensors and actuators to create investigations and used data flow software to run and control the experiments. In this way students were able to engage as data producers instead of merely data collectors, which impacts students' future engagement in scientific and computing practices, even for those who do not continue in these professional disciplines or careers.

The ability to collect large data sets easily can help offset potential shortcomings with using curated data sets collected by others. Utilizing data streams that they produce themselves allows students to interact with big data as authentic scientists conducting their own experiments (Kahn & Hall, 2016). Moreover, having students use and program sensors to collect their own data can be a promising way to support CT integration in science (Gendreau Chakarov et al., 2019a).

Integrating Computational Thinking in Science Classrooms

To integrate CT into the K-12 curriculum, the definition of CT must be detailed enough so teachers understand how to implement specific lessons and assess student thinking (Barr & Stephenson, 2011; Grover & Pea, 2013). Several frameworks exist for describing CT (see also Brennan & Resnick, 2012); however, these frameworks were developed by computer scientists in the context of programming activities. While general frameworks can help build understandings of CT across disciplines and support connections between disciplines, they lack specificity for teachers to use them as a tool for curricular integration.

For this project we built on the Computational Thinking in Mathematics and Science Taxonomy developed by Weintrop et al. (2016) to define what CT looks like in K-12 mathematics and science classes. The taxonomy was designed based on an extensive literature review, descriptions of CT-infused lessons, and collaborations with STEM professionals and K-12 STEM teachers to understand what CT looks like in different STEM discipline areas.

Weintrop et al. (2016) proposed four CT categories: data practices (different ways that students should be able to work with and understand data), modeling and simulation practices (students design, construct, and assess computational models to build explanations for phenomena), computational problem solving practices (students explore how computer science concepts such as modularity and abstraction provide a lens through which to investigate scientific problems), and systems thinking practices (students investigate the system as a whole, the different levels of the system, and relationships within the system).

The categories are labeled as “practices” to align with the language used around the science and engineering practices in the NGSS (NGSS Lead States, 2013). Given that Weintrop’s framework is designed to support the integration of CT in science classes and uses language similar to the science and engineering practices familiar to middle school teachers, it served as the initial framework for CT for the project.

Science Education and Curriculum Design

Science education has been undergoing reforms throughout the last decade beginning with the development of *A Framework for K-12 Science Education* (NRC, 2012), which introduced the three dimensions of science education: disciplinary core ideas (DCIs; see Overview), science and engineering practices (SEPs; see Appendix F), and cross cutting concepts (CCCs; see Appendix G). This framework provided the basis for the development of the NGSS (NGSS Lead States, 2013). One major goal of these recent reforms is to make science class more like the work of scientists (Penuel, 2016) by combining the learning of content and practice (Bybee, 2014) and increasing the use of tools that more closely represent the tools used by practicing scientists (NRC, 2012).

The DCIs represent the big science ideas in four core disciplines (Earth Science, Life Science, Physical Science, and Engineering) and apply at all grade levels. SEPs represent how scientists engage in their everyday work and include practices such as asking questions and defining problems, planning and carrying out investigations, and using mathematics and computational thinking. CCCs represent how students can think and reason about scientific phenomena. These concepts provide different ways for students to examine phenomena, such as analyzing data by looking for patterns or looking to support a cause-and-effect relationship.

Performance expectations (PEs) incorporate pieces of all three dimensions of science instruction: DCIs, SEPs, and CCCs. PEs are broken down by grade band and represent what a student should know by the end of the year.

Penuel and Reiser (2018) outlined seven principles for designing curriculum aligned to the NGSS and considered how these principals might lead to changes in instructional strategies. They advocated for integrating the three dimensions throughout the curriculum instead of teaching content and practices separately. Phenomena should anchor the curriculum to support incremental sense-making and knowledge building and avoid a disjointed sequence of lessons that teach content before practical applications. Last, the curriculum should have built-in supports to enable students' equitable participation, guidance for teachers to use students' ideas as building blocks, and tools to support teacher learning.

One instructional design technique that has proven successful in adhering to these principles is the creation of storylines (Reiser et al., 2015; Shelton, 2015; Shwartz et al., 2008). Storylines (Next Generation Storylines, n.d.) are created before individual lessons to serve as unit guides and ensure coherence and incremental knowledge building. The first step is choosing the set of performance expectations for the unit. The next step is to identify a phenomenon to anchor the unit.

A scientific phenomenon is something that can be observed in real life, can use scientific knowledge to learn about, and construct explanations for observations of it (Achieve, 2017). Some examples of phenomena include how the moon affects tides, what happens during a car crash, or how a maglev train works.

In developing storylines, design teams strive to predict likely student questions and provide a sequence of ideas and activities that sustain continuity and interest throughout the unit (Reiser, 2014). They engage in portions of the lessons themselves to understand the kinds of questions students might generate and how students might categorize and prioritize them into investigable categories on what is called a driving question board (Weizman et al., 2010). From those questions, they build out lessons in the storyline that correspond to the questions based on the prioritization process.

The idea is first to develop a high-level storyline and then go back to develop a sequence of lessons based on the storyline, thereby enabling a coherent lesson sequence (Reiser, 2014; Penuel & Reiser, 2018). Having a coherent storyline helps students make sense of the science they are learning (Reiser et al., 2015; Schwarz et al., 2017; Shwartz et al., 2008). The goal is to ensure that students are drivers of the scientific inquiry process, rather than simply learners of science (Penuel, 2016).

A New Professional Development Model: The CT-Integration Cycle

In order for science and STEM teachers to learn to teach with storylines and programmable sensor technology in an effort to integrate CT, they need sustained professional learning experiences. The CT-Integration Cycle is an approach developed by our research team to help build teacher capacity to implement CT-integrated instructional activities.

The CT-Integration Cycle draws on and combines elements of two successful professional development models: collaborative design (codesign) for the development of science curricula (Penuel et al., 2007; Penuel & DeBarger, 2016; Penuel et al., 2018; Reiser et al., 2000) and the Problem-Solving Cycle (http://www.sfusdmath.org/problem-solving-cycle.html), in which teachers move through iterative cycles of planning, teaching, and reflecting (Borko et al., 2008; Jacobs et al., 2007, 2009).

Codesign involves researchers and practitioners working closely together to develop novel educational innovations. It is a productive curriculum building experience (Fishman et al., 2013), especially for science curriculum (Penuel et al., 2018), providing a way to increase teachers' engagement with and investment in the curriculum and bolster their feelings of agency around the curriculum (Severance et al., 2016).

The codesign process draws on teachers' ideas and expertise as an integral component of the development of both storylines and their associated lessons and classroom resources (Penuel et al., 2007). As such, the process helps ensure that the resulting units are both feasible and appropriate for teachers' local school context.

One important aspect of the CT-Integration Cycle includes working collaboratively with practicing science teachers to codesign storylines (Reiser et al., 2015; 2016) that incorporate CT practices and programmable sensors. Selecting a scientific phenomenon to anchor the storyline is critical for ensuring student motivation and promoting deeper levels of student thinking (Blumenfeld et al., 1991).

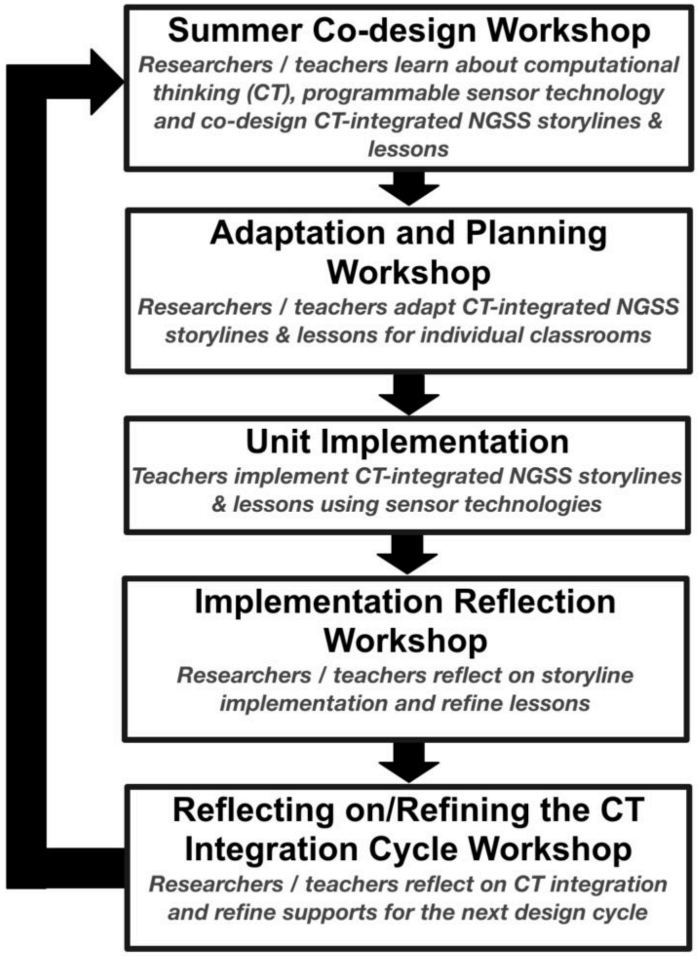
These phenomena should allow for CT-integration, align to targeted PEs, and be relevant and interesting to students. The Schoolwide Labs project codesigned several NGSS-aligned instructional unitsthat encourage students to think computationally as they make sense of scientific phenomena using portable, affordable, and programmable sensor technology (https://www.colorado.edu/program/schoolwide-labs).

The Problem-Solving Cycle model of PD (San Francisco Unified School District Mathematics Department, n.d.) focuses on supporting teachers to become part of an ongoing learning community that engages in mathematical problem solving, examines video of classroom teaching, and shares ideas about teaching and learning (Borko et al., 2015). During each cycle, teachers collaboratively solve a rich mathematical problem, develop plans for teaching that problem to their own students, implement the lesson, and reflect on their experiences through the examination of video clips and student artifacts.

As they participate in successive iterations of the model, teachers can gain new insights and continually add to their knowledge base (Koellner et al., 2007). Research suggests that participation in the Problem-Solving Cycle leads to incremental gains in teachers' knowledge, improvements in instructional practice, and has at least a small positive impact on their students' mathematics achievement (Borko et al., 2015; Koellner & Jacobs, 2015).

The CT-Integration Cycle combines key features of curricular codesign and the Problem-Solving Cycle, as illustrated in Figure 1. Codesign supports the development of new CT-integrated curricula and activities, while the Problem-Solving Cycle provides a structure for teachers to examine collectively their classroom implementation of the co-designed curriculum.

Figure 1 CT-Integration Cycle



Similar to the Problem-Solving Cycle, the CT-Integration Cycle is a practice-based approach to teacher professional development (PD), meaning that problems of practice ground teachers' activities and interactions during the workshops, which can lead to increases in self-efficacy related to CT (Mason & Rich, 2019). As Fishman et al. (2017) explained, practice-based PD "centers teacher learning on the core tasks and activities of teaching rather than knowledge or theory" (p. 224).

A key element of practice-based approaches is the inclusion of professional learning tasks – such as curricular materials, classroom video, and student work samples – that afford opportunities for teachers to think through pedagogical problems and solutions (Silver et al., 2007). Teachers who take part in the CT-Integration Cycle engage as a learning community in a variety of professional learning tasks as they move through the process of designing curricular materials, implementing those materials, and using video clips and student artifacts to reflect on notable aspects of teaching and learning.

In addition to activities that are practice-based in nature, the manner in which teachers engage in these activities during workshops is critical to maintaining a strong focus on teaching and learning. To this end, an important component of the CT-Integration Cycle is that teachers frequently take the perspective of their students, including considering how their students would likely respond to specific curricular materials and pedagogical practices.

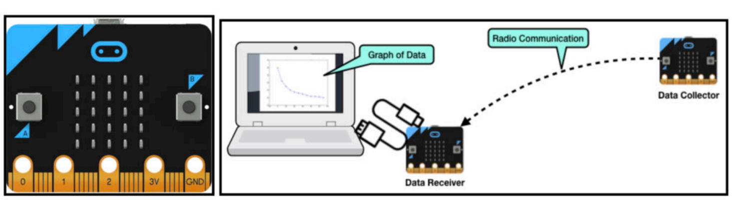
During many activities, some or all of the teachers intentionally wear a "middle school student hat" to actively consider the effectiveness of a particular resource of instructional routine from a student lens and then move to wearing a "teacher hat" when they engage in discussions about how to best support their students (as recommended in Cunningham & Carlsen, 2014; Klein & Riordan, 2011). Working in a student hat has been used as an effective PD tool when introducing teachers to unfamiliar computing concepts (Goode et al., 2014) and has also been successful as part of the process of codesigning science curriculum (Campbell et al., 2014; 2019).

The CT-Integration Cycle consists of multiple workshops carried out with enough flexibility built in to accommodate the needs of any given group of teachers. Each cycle consists of a 3- to 5-day summer design workshop and three to four full-day workshops throughout the school year. In this paper we describe one full iteration of a CT-Integration Cycle that took place during the second year of the Schoolwide Labs project, to highlight the general nature of this professional learning approach as well as the specific experiences of the participating teachers.

This iteration of the CT-Integration Cycle centered on the codesign, implementation, and reflection of a CT-Integrated unit, the maglev train storyline (https://www.colorado.edu/program/schoolwide-labs). As part of the maglev train storyline students use micro:bits (see Figure 2) to measure magnetic forces. The micro:bit (from https://microbit.org) has an onboard magnetometer sensor that students can program to control various aspects of their data collection and customize how they display the relevant data.

Using the micro:bit supports computational problem solving, as students see and analyze data in real time. Throughout the maglev unit students may authentically engage in several of the CT practices defined by Weintrop et al. (2016) as they investigate questions and construct explanations related to the scientific phenomenon of magnetic levitation.

Figure 2 The Sensor Platform Used in the CT-Integration Cycle



The sensor platform includes two micro:bits that enable radio communication and can be connected to a computer for real time data visualization.

Method

Participants and Context

This article describes a small exploratory case study (Baxter & Jack, 2008; Yin, 2010) to develop and refine the CT-Integration Cycle, as well as to design and pilot CT-integrated curricular materials and resources.This case study was bounded (see also Stake, 1995) around one iteration of the CT-Integration Cycle, which took place over the course of one school year and centered around the maglev train storyline.

The five participants who took part in the iteration included one integrated STEM teacher (Carolyn) and four science middle school teachers (Trent, Tracy, Matthew, James; pseudonyms are used for all teachers and school district administrators). In this school district, integrated STEM is a required elective course that meets less frequently than regular classes and focuses on topics such as civil engineering, introductory programming, and electronics. The teachers implemented the maglev train storyline with a total of 293 students. Teacher demographics are shown in Table 1.

Table 1 Participating Teacher Demographics

Demo-graphic	James	Matthew	Carolyn	Trent	Tracy
Gender	M	M	F	M	F
Teaching Experience	3	3	15	3	12
Teaching Experience in 6-8 Science or STEM	3	2	5	3	4
Grade Levels(s)	7	6,7,8	5,6,7,8	8	6
Subject(s) Teaching	Life science	Earth Science, Physical Science, Integrated STEM, Basic CS	Integra-ted STEM	Physical Science	Life Science, Earth Science, Physical Science, Integrated STEM
Teaching Credential(s)/ Endorsements	Science	English/ Language Arts, Science, Social Studies, Technology, Other	English/ Language Arts, Math	Science	Other credential

All teachers worked in the same large urban school district in the western region of the U.S. Carolyn and Trent had taken part in an iteration of the CT-Integration Cycle during the previous school year. The rest of the teachers were new to the project, and they were novices with respect to storylining, using sensor technology, and CT. Prior to joining the project, all of the new teacher participants took part in a multiday district workshop focusing on the NGSS and storylining.

Four facilitators (referred to in the paper as Facilitators 1, 2, 3, and 4) who were also members of the research team led the workshop. Two science and STEM coordinators from the school district also attended and participated in most of the workshops (Sarah and Arnold).

Data sources

PD Observations

The PD included three full-day workshops in summer 2018, two full days of planning workshops in fall 2018, and two full-day reflection workshops in spring 2019 (see Table 2). The workshops were video recorded and at least two members of the research team took detailed observation notes with a focus on teachers' experiences related to CT and CT integration. These notes provided a record of workshop activities for the full research team to reflect on strategies utilized during teacher learning and to iteratively revise activities in subsequent teacher workshops.

Table 2 CT-integration Cycle Data Collection Overview

CT Integration Cycle Phase	Activities During Maglev Train CT Cycle	Timeframe	Data Collected
Summer Co-design Workshop *Researchers / teachers learn about computational thinking (CT), programmable sensor technology and co-design CT-integrated NGSS storylines & lessons*	Teachers learned how to program and use the micro:bit. Teachers and researchers worked together to select the maglev train phenomenon and began co-designing the maglev CT integrated storyline	Three day workshop	PD Observations, Teacher Reflections, Focus Group Interviews
Adaptation and Planning Workshops *Researchers / teachers adapt CT-integrated NGSS storylines & lessons for individual classrooms*	Teachers explored and unpacked CT and CT practices. Teachers co-design and refine maglev CT integrated storyline lessons. Teachers planned and practiced using the micro:bit for the maglev storyline lessons.	Two single day workshops	PD Observations, Teacher Reflections, Focus Group Interviews
Unit Implementation *Teachers implement CT-integrated NGSS storylines & lessons using sensor technologies*	Teachers implemented the maglev CT integrated storyline. Researchers observed and provided support for pedagogy and technology.	Three weeks of classroom instruction	Classroom Observations, Student Surveys, Teacher Interviews
Implementation Reflection Workshop *Researchers / teachers reflect on storyline implementation and refine lessons*	Teachers discussed and reflected on different aspects (i.e. science and NGSS alignment, student engagement, CT and sensor usage) of implementing the maglev CT integrated storyline.	One single day workshop	PD Observations, Teacher Reflections, Focus Group Interviews
Reflecting on/Refining the CT Integration Cycle Workshop *Researchers / teachers reflect on CT integration and refine supports for the next design cycle*	Teachers reflected on their CT learning during the maglev CT cycle and began to plan for the next cycle by brainstorming a new CT integrated sensor immersions storyline focusing on the sensors.	One single day workshop	PD Observations, Teacher Reflections, Focus Group Interviews

Classroom Observations

During each teacher's implementation of the maglev train storyline, portions of the unit that specifically integrated CT and sensor usage were video recorded. In addition, members of the research team took time-stamped field notes during their observations and again after reviewing the video footage. These observations focused on how the teacher launched the lesson, how students were engaging in the lesson activities (e.g., How does the teacher transition to the next activity/task? What knowledge building tools are used? When and how do students work individually, in pairs, in small groups, or in the whole group? What questions do students pose to the teacher, and How does the teacher respond?) and how the teacher closed the lesson (e.g., What is the transition between the activity and end of the period? Does the teacher — or do the students — refer to the Driving Question Board, a previous lesson, or what they might do next time?). These observation notes allowed the researchers to understand how the lessons unfolded during implementation and to consider potential modifications to the storyline.

Student Surveys

Students of teachers who implemented the maglev train storyline completed brief surveys three times during the unit, after the first lesson, and in two subsequent lessons (Bryk et al., 2015). The closed-ended survey items asked for students' feedback on their sense of participation in science and CT practices. These short surveys (see Table 3) were useful in gauging students' perceptions of the coherence of the unit, contributions they made during class, and relevance of the topic to them personally and to their community (Penuel et al., 2018). Understanding how students experience their curriculum and classroom instruction has become an important part of both school improvement efforts and teacher professional learning (Bryk et al., 2015; Penuel et al., 2018).

Table 3 Student Experience Survey Items

Coherence Questions	Relevance Questions	Contribution Questions
I understand how what we did in class today ties to the bigger picture for what we're studying in this unit.	Today in class I felt like a scientist.	Did you share any ideas out loud today to the whole class, a small group, or a partner?
I have ideas about what questions we should investigate next.	I think my teacher should have us use sensors more often to conduct investigations.	If you shared ideas out loud today, did any of your ideas influence the class or help others?
With the help of our teacher, we used our driving questions to guide what we did in class today	What we did in class today matters to me because: (circle one option that best describes your feelings) - This material is interesting. - It will be useful to me in the future. - It is important to my everyday life and/or people I care about. - It will help me get a good grade. - It doesn't matter to me.	I learned more in class today because other students shared their ideas or opinions?

Teacher Reflections and Interviews

During each workshop teachers were prompted to write individual reflections on topics specific to that workshop. These reflections were written in Google Docs so they could be easily accessed and analyzed later. Likewise, all of the teachers were interviewed in small groups during or after each workshop in the form of focus group conversations with a member of the research team. The reflections and focus group interviews elicited teachers' perceptions of the workshop activities and their own learning, their emerging understanding of and comfort with CT, and their thoughts and concerns related to integrating CT.

Additionally, teachers were individually interviewed once by a member of the research team following their completed implementation of the maglev train storyline. These semistructured debrief interviews captured teachers' thoughts about how well the implementation worked, student engagement in the unit, and challenges and successes related to CT integration and sensor usage. The focus group and debrief interviews were audio-recorded and transcribed. Examples of reflection, focus group, and debrief interview questions can be found in the appendix.

Data Analyses

Workshop data for this case were analyzed using a constant comparative method (Creswell, 2013; Glaser & Strauss, 1967). Members of the research team used open coding to analyze data from each workshop to determine what topics or themes might emerge that accurately conveyed the nature of the activities teachers took part in (as recommended in Merriam, 2009; Strauss & Corbin, 1990). This qualitative analysis of each workshop involved viewing the videos, workshop artifacts (such as presentation slides, agendas, teacher reflection documents, and focus group interview transcripts), and observation notes.

At least two researchers analyzed each workshop and discussed what they had noted with the research team (as recommended by Merriam, 2009; Stake, 1995). After several iterations, we agreed to document the following seven nonmutually exclusive themes: pedagogy, storylining and co-design, NGSS, computational thinking, sensor usage, community building, and considering student artifacts.

First, we created analytic memos noting when instances of each theme were explicitly evident. We then reviewed each other's analytic memos and collaboratively considered their interpretations, ultimately coming to consensus on whether and when the workshop focused on each theme (as recommended in Merriam, 2009; Stake, 1995). Finally, for each workshop, we calculated the percentage of times (occurrences of a given topic/total number of occurrences across all topics) that each topic was documented.

We also used the analytic memos to generate descriptions and illustrative vignettes (Rogers, 2018; Stecher et al., 2006) that captured critical moments within each workshop. A "critical moment" was defined as a period of time in which teachers deeply engaged in one or more of the identified themes and clearly expressed their views about this engagement either as part of a conversation that took place during the workshop, in a written reflection, or in an interview afterwards. We reviewed each other's descriptions and vignettes, agreed on a set to include in the paper, and then collectively added to or revised the descriptions based on their own review of the relevant data.

A similar process was undertaken to generate the descriptions of two teachers' classroom implementations of the maglev train storyline. These descriptions were written based on at least two authors carefully reviewing the relevant classroom video, field notes, teacher interview transcripts, and student survey data and writing analytic memos that captured the implementation from both the teachers' and students' perspectives.

Results

In this section is a summary of teachers' overall experiences and then an discussion of these experiences in each phase of the CT-Integration cycle. The discussion section includes highlights of how these experiences addressed each of the research questions.

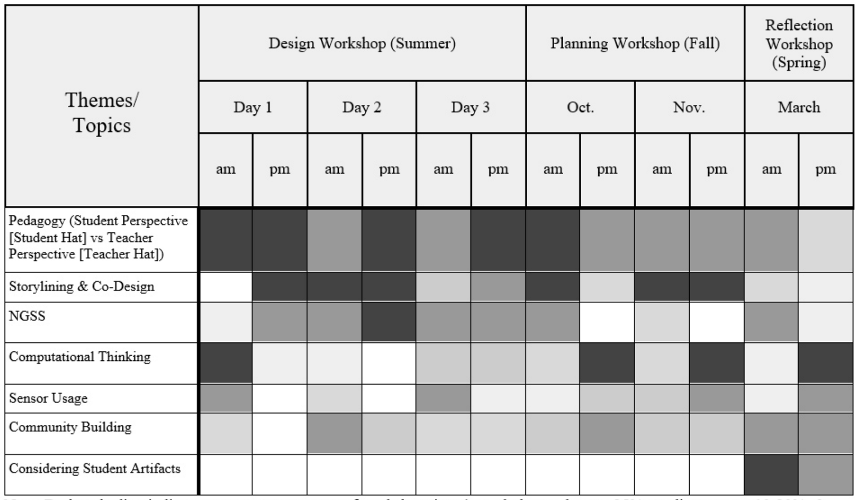
Teachers' Overall Experiences in the Maglev Train CT-Integration Cycle

Figure 3 shows a summary of the time teachers spent in different themes over the course of the maglev train CT-Integration Cycle. The table describes when and how often teachers engaged in various topics during the six full-day workshops. The table shows the workshops as broken into AM and PM sessions because those time periods focused more or less intensely on different themes. Displaying the findings at this scale helps to provide an overview of teachers' experiences throughout the course of the professional learning cycle.

Figure 3 shows that pedagogy was a major focus throughout the workshops and served as the backbone of this iteration of the CT-Integration Cycle. Pedagogy included taking a student perspective as well as a teacher perspective on a given instructional issue. With pedagogy as a backdrop, the group focused on covering topics related to storylining and codesign, NGSS, CT, and sensors. Storylining and co-design played a large role during the summer workshops, and they also were heavily targeted during the later workshops (often in form of revising or adapting the existing storyline).

Looking across the cycle, the NGSS was clearly emphasized more often during the summer workshops, whereas CT was emphasized more often during the school year workshops. A focus on sensor technology usage tended to correspond with an emphasis on CT. In all of the workshops some degree of emphasis was placed on community building, and in the last workshop was a strong focus on student artifacts.

Figure 3 Summary of Teachers' Experiences During the Maglev Train CT-integration Cycle: Degree of Occurrences of Seven Themes



Note: Darker shading indicates a greater percentage of workshop time (e.g., darkest color = > 25%, medium grey = 10-20%, & clear = < 1%)

Teachers' Experiences in the Summer Codesign Workshop

In the Schoolwide Labs project, the three summer codesign workshops resulted in the creation of the maglev train storyline. These workshops involved deciding how to anchor the storyline; taking part in routines to anticipate, categorize, and prioritize students' questions that will drive subsequent student investigations; using those questions to organize the storyline; and planning a rough outline of at least some lessons based on the storyline. Vignettes such as the following (indented to emphasize teachers' workshop experiences) provide glimpses into how participating teachers engaged in specific workshop activities:

Facilitators stressed that the workshops were a space for codesign, not one directional "development." Facilitator 3 said during her introduction to the project, "We will be creating, together, a storyline unit, hopefully today," indicating the planned work would be done as a group. Sarah, the district administrator in charge of science, echoed this sentiment later when she introduced herself and the goals of the project. Sarah stated, "We were able to survey students [about possible phenomena to focus the storyline one]. ... So, we used student data to figure out what kids are excited about. ... So, ideally, over the next few days we are going to look at those phenomena and create storylines around those."

This messaging created an emerging space that highlighted (a) the direct connection to students and (b) the activity goal of codesigning, particularly creating storylines together as teachers and researchers. Although the participating teachers knew sensor technology would be a core component of the storyline they codesigned, none were familiar with the micro:bit. Before they began generating the storyline, the group took part in a series of activities to become acquainted with the capabilities of the micro:bit and the types of data it could collect.

The teachers had various programming experience ranging from none at all to teaching basic coding through programs like Scratch. Although some teachers had used sensors, none had previous experience with the micro:bit or the block coding platform, Makecode (https://makecode.microbit.org/), that it paired with.

Teachers broke into three groups, each having one teacher more experienced with programming, and engaged in a series of programming activities. These student-hat activities allowed the teachers to interact with the micro:bit and learn how to program it from a beginner student-user perspective. Teachers then shifted into their teacher hat and discussed the challenges they faced, challenges their students might face, and how they could support their students through these challenges.

Teachers spent most of the morning unboxing and discussing the micro:bit. Once they were familiar with the hardware and software, Facilitator 1 challenged the teachers to write and deploy a program that made the LEDs on the micro:bit scroll the word “HI”. As they worked on this task, she offered tips and strategies about the logistics and mechanics of Makecode that could make the programming easier.

A few teachers became frustrated that their program was not working. One teacher described their issue as, “I don’t think that your [Facilitator 1] explanation is wrong, I think you’re doing a great job explaining it. My computer’s just not doing what you’re telling me it should do.” Facilitator 1 acknowledged the struggles inherent in learning computer science programming:

> It is very uncomfortable at the beginning if you don’t know exactly what you’re doing. And that is OK, and that’s what I’m trying to convey here. It was uncomfortable for me when I was introduced to the Makecode interface and I have been programming for 10 years of my life. … I know that [your students] are going to have a lot of questions when they’re messing around and a lot of this is preparing you to understand the feelings that your kids are going to have.

Facilitator 1 unveiled the next programming challenge: to make a variable laden program that displays a rock, paper, or scissors chosen at random when the micro:bit is shaken. Once the participating teachers all had a working program, they got out of their seats to play the micro:bit mediated Rock, Paper, Scissors game with a partner.

Trent and his partner played against each other a few times before Carolyn and her partner approached to switch teams. Carolyn and Trent paired up, and after two battles Carolyn suggested that she was not sure if her rock was chosen a second time because “it may not have changed.” Trent shared that was why he made his selected object disappear after a bit.

Carolyn asked, “What does that look like on there [the computer]” and they stepped over to his computer. Trent leaned into his computer, saying, “That way I know it always changes,” and he scrolled down to show Carolyn that his code had a wait block with 5,000ms. Seeing this, Carolyn asked, “Is 5,000 10 seconds?” and Trent responded, “It's 5 seconds not 10 seconds.”

By this point, both of their original partners had surrounded the computer, with Carolyn’s original partner also wondering what Trent did. Trent’s partner shared that 5 seconds feels like a long time and Trent agreed saying, “Yeah, that’s why I want to make it a button or something.” Carolyn, still looking at the code, added, “Yeah, I wanna do that,” before stepping away from the computer and heading back to her seat.

This cascading interaction was an important moment in the teachers’ trajectories in the CT-Integration Cycle. The emergent moment of collaboration, where Trent shared his logic and code with the other teachers, became a building block for the collegial relationship all the teachers and researchers developed over the course of the year. Although brief, the conversation signaled that they were all going through this learning process together, and ultimately developed new knowledge along with useful curricular resources and pedagogies for their classrooms. Trent, Carolyn, and the other teachers engaged in an authentic collaborative interaction that involved productive struggle, much in the same way their students were likely to experience when first introduced to the micro:bit, just as Facilitator 1 posited earlier in the session.

Teachers' individual written reflections after they took part in these workshop activities suggested that they gained a nuanced understanding of what their students would encounter when using the sensor technology. For example, one teacher reflected,

> I needed to think critically to determine how my computer can tell the micro:bit what I want it to do using the block coding. And systems thinking, I needed to define the different systems within the block coding system in order for the micro:bit to properly perform the task I was given.

Another teacher noted, “I had to use ‘trial and error’ methods in order to see what would work and what wouldn’t.”

However, in their reflections teachers also expressed a number of questions and reservations about integrating CT into science instruction, which they hoped would get resolved throughout their continued participation in the CT-Integration Cycle. These concerns included the following:

- “How can we create experiences that are broad enough to engage a variety of learners, including ELL [English language learner] students, and for students of all grade levels?”
- “How am I going to teach my students how to code the micro:bit when I know so little about it myself, and how much time will I need to spend to teach students this?”
- “How can STEM and science teachers work together to integrate CT, since our classes have different goals?”

After learning about the micro:bit, the teachers moved into storylining by considering which phenomenon they should use to anchor their codesigned curricular unit. Courtney and Trent had already taken up this issue at their last workshop (during the previous school year) and selected several options, which they posed to their students in the form of a survey.

Two candidate phenomena on the survey stood out as garnering particularly high student interest. After teachers constructed models and written explanations from a student perspective for both phenomena, they agreed that one of the phenomena was too complex for middle school students and would offer fewer opportunities for CT engagement and sensor usage. The magnetic levitation phenomenon was selected since it provided opportunities to use sensors in novel ways and the teachers felt confident their students would be able to learn and explain the concepts related to a maglev train.

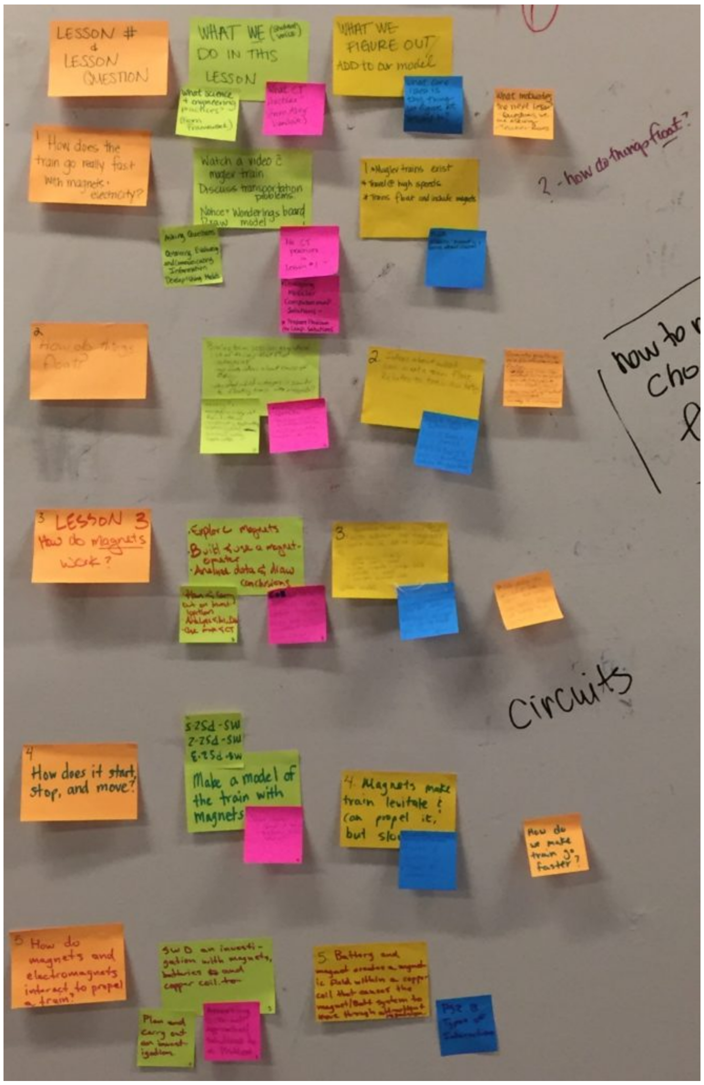
To generate an initial sequence of student investigations for the maglev train storyline, the group engaged in several structured activities facilitated by members of the research team with the teachers while wearing their student hat. The teachers watched video clips describing a maglev train in Shanghai, China, and a train-like object formed by a battery and magnet that can move through a coiled copper wire.

Teachers were prompted (as their students would be) to write down what they noticed in the video and what they wondered about the videos on sticky notes, and they shared these observations with the whole group. The teachers then categorized their questions and gave each category a name that summarized the essence of the questions in the category (see Figure 4).

Figure 4 Example of a Driving Question Board with Teachers' Question Categories for the Maglev Train Storyline

Next, the group discussed how to sequence students' investigations across the categories based on the questions that seemed to make the most sense to answer first, second, and so on. Together, these steps served to construct the skeleton of the maglev train storyline (see Figure 5) and helped ensure that it would have a coherent flow.

Figure 5 Skeletal Outline of the Codesigned Maglev Train Storyline



Late in the morning of the 2nd day of the summer workshop, teachers returned to the maglev train storyline and began thinking about students' first investigation, which they had previously agreed should address the question, "How do trains go really fast using magnets?" Teachers put on their student hat to consider this question from a student perspective.

Teachers engaged in a lengthy discussion about the mechanics of how magnets can make trains both float and move. Some still had questions about how magnets propel a train, so Facilitator 2 provided a more detailed explanation. Based on this conversation, the teachers decided that their students should first gain an understanding of how magnets enable objects to float before they move into a consideration of how magnets can propel trains.

Throughout the development of the storyline, teachers continued to coconstruct curricular decisions while moving back and forth between their teacher hat – in which they gained new knowledge and weighed instructional choices – and their student hat – when they put themselves in their students' shoes. Another important consideration was how to motivate students' usage of the sensors in authentic ways, particularly using the magnetometer to measure the strength of a magnetic field.

Facilitator 3 asked the group to think about how they could help their students identify a need to use sensors to quantify the degree to which magnets attract and repel. Matthew mentioned that iron filings could be useful for students to see what is going on since the filings would form the shape of the magnetic field. The teachers began to brainstorm how students can transition from working with iron filings to asking questions they could answer by using sensors.

Here the codesign process integrated science with CT. The teachers wanted their students to naturally see the need for programmable sensors in their scientific investigations, so they strove to design the curriculum accordingly.

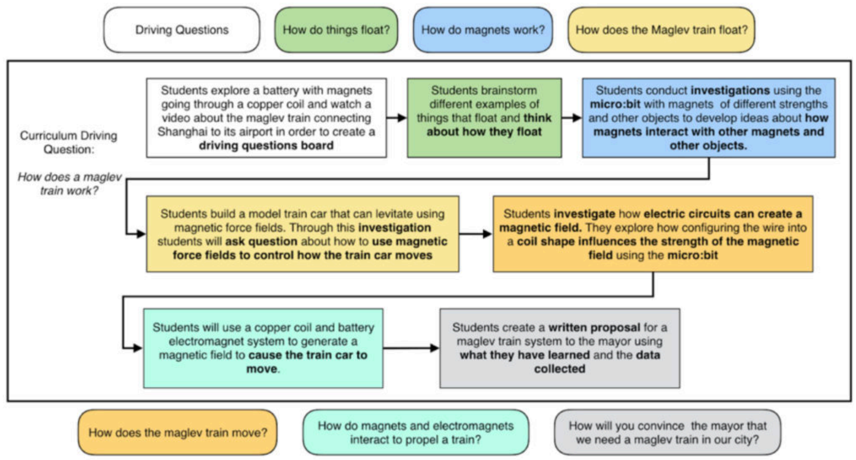
Teachers discussed the specifics of how to get the micro:bit to work as a magnetometer and what the student experience would be. One teacher suggested having the magnetometer act like a metal detector and make it beeping sound when it is held over a magnetic field.

This example again illustrates teachers integrating CT into the process of designing curriculum for authentic scientific inquiry. Next the group talked about how the emerging curriculum related to performance expectations for their students.

By the end of the summer codesign workshops, the teachers had constructed a storyline that had a clear line of student-driven investigations and involved the use of sensor technology at critical junctures (see Figure 6). The teachers agreed that the storyline should have a focus on place (as also in Buxton, 2010) to increase the unit's relevance to students and support their engagement in the phenomenon.

Correspondingly, the storyline included a connection to the traffic problems experienced by the students' local communities that could be mitigated by a high-speed maglev train and concluded with students writing a proposal to their mayor about the ideal location for a maglev train in their city. After the summer workshop we took the storyline skeleton and began to construct detailed lessons and supporting materials.

Figure 6 Overview of the Maglev Train Storyline



Teachers’ Experiences in the First Planning Workshop

Codesigning continued as part of the two planning workshops with teachers, providing feedback on the specific lessons, investigations, and sensemaking activities and discussions that were included in the maglev train storyline. At the end of the first planning workshop, the group engaged in a lengthy conversation about what CT means and how students’ CT can be fostered as part of CT-integrated curriculum such as the maglev train storyline.

Facilitator 1 asked the teachers to write down their questions about CT on sticky notes and then sorted them into categories, much the same way teachers began working on the maglev train storyline by writing down what they noticed and wondered. Teachers questions fell into the following categories:

- “What shared vocabulary do we need?”
- “How can we take into account vertical integration across grade levels?”
- “What does CT look like in the maglev train storyline?”
- “What are concrete examples of what CT would look like in our classrooms?”

The teachers then took part in a whole-group discussion in which they reflected on these questions and came up with additional ones.

Teachers shared some of the things they had noticed in their classrooms with regard to gender and computing. Tracy said she found that girls often got discouraged when they were faced with a challenge and deferred to the boys for expertise. Trent countered that he did not notice that sort of gender-based difference in his science classes. Carolyn added that girls seemed drawn more to the storytelling components of her lessons while boys appeared more interested in robotics.

Matthew offered that having students write down and share their questions helped with democratizing access and as well as preventing extrovert bias. Sarah reported that she had used roles (such as pair programming) to help with equity, and if she noticed any concerning gender patterns she assigned students new roles to help balance differences in participation by gender.

This discussion helped the teachers coconstruct a narrative of how CT-integrated curriculum can support a variety of related goals, such as attending to and promoting equity, as well as offering students access to meaningful STEM experiences in their classrooms. The conversation also allowed teachers to talk openly about their concerns and receive both empathy and support from their colleagues as they embarked on uncharted waters to teach new curriculum in new ways using new technology.

While wrapping up the day's session, Facilitator 1 asked the teachers what they might need going forward. Arnold, one of the district STEM coordinators, suggested having access to complete versions of the Makecode programs used in the maglev train storyline, so they would not have to teach coding to the students. Facilitator 1 responded that she thought it was important for students to understand how programming works, at least in a basic way, so that they have some sense of what the sensors are doing. Trent noted that the main thing he has been struggling with during the workshops is not knowing the exact programming steps and not understanding why the code works the way it does. He added that he would be more comfortable teaching his students basic programming if he had a deeper understanding of how the coding worked.

Arnold and Trent, along with some of the other teachers, were especially concerned about teaching programming for the first time to their middle school students as part of the maglev train storyline. This concern led to serious doubts about using programmable sensors as an integral part of the unit. Trent was even more blunt in his written reflection: "At this point I'm not bought into how the sensors play a vital role in the storyline – why are we collecting the data, what does the data help us learn, what can we conclude with the data?" As a science teacher with limited coding experience, Trent had a clear need for more support with the CT part of the curriculum to fully integrate it with the science behind maglev trains.

Arnold revised his request for completed programs to a request for tutorials in which students would be provided with guidance but would still need to make decisions relating to the block coding. As part of the tutorials students would not be given complete programming solutions, but rather they would serve as a scaffold to support them in developing an understanding of how the coding worked. Facilitator 1 suggested also making videos to support students' programming efforts, and multiple teachers agreed that these sorts of resources would be helpful.

This exchange illustrates the group working together to determine what an appropriate level of support would be for integrating CT into their curriculum. The teachers recognized a gap in their own knowledge as well as a gap in the resources developed for the maglev train storyline. Through brainstorming and collaboration, they ultimately generated ideas for how to begin to bridge both gaps.

Teachers' Experiences in the Second Planning Workshop

The second planning workshop was the last meeting with the teachers before they began implementing the maglev train storyline. In the morning, teachers reviewed each lesson of the storyline by going through select portions wearing a student hat and then debriefing their experiences wearing a teacher hat.

Teachers engaged in a student hat activity where they programmed two micro:bits to transmit data using a radio function. In this activity one micro:bit sends collected data to a micro:bit that receives the data and is connected to a computer so it can create a graph showing the strength of the magnetic field created by fixed magnets. This programming activity was anticipated to be challenging for students, especially the step involving programming the micro:bits to send data to each other to create a graph. In the previous workshop teachers had programmed the magnetometer to take readings of a magnetic field, but they recorded those readings by hand rather than programming the computer to keep track of the values and construct a graph.

As teachers began working in small groups to complete the programming challenge, Facilitator 1 reminded them about the planning activity sheet that students are expected to use to create a programming plan before they actually write their code. Using the radio function to send data from one micro:bit to another micro:bit connected to a computer proved very challenging for the teachers and required significant assistance on the part of the facilitators. Carolyn and Matthew, the two STEM teachers who had more prior programming experience, helped the other teachers.

During a discussion after the group completed the activity, several teachers expressed concern about their students' ability to program the micro:bit and their own ability to support them to successfully program the micro:bit. Carolyn attempted to alleviate these concerns by describing her previous successful experiences implementing programming projects. Although Tracy was a teacher who struggled with the programming experience, she remained enthusiastic about using the activity in her classroom. Tracy felt confident that her students would know more than her about the technology and would be able to assist each other

Part of the challenge with using the magnetometer in the maglev train storyline is making sure that students see the need for using it (rather than being told to use it by the teacher) and maintaining that motivation while engaging in the programming component. Therefore, another aspect of the teacher hat discussion centered on how to create and maintain a connection between computational tools and processes to the focal science content.

Some teachers continued to express misgivings about the integration of these various components. For example, Trent stated in his postworkshop written reflection,

> I feel most confident about the launch, the driving question board, and letting the students drive the lessons through their questioning. My biggest concerns are around the programming of the micro:bit – I can do it, but I don't necessarily understand why I'm doing the things I need to do.

Similar to the feelings he expressed in the first planning workshop, Trent reported being more confident with elements of teaching related to science and less confident around computing. Despite his concerns around not knowing why the sensors need to be programmed in a specific way, Trent began to exhibit a more sophisticated understanding of CT as encompassing not only programming sensors but as involving data collection and data manipulation. Trent reflected,

My understanding of CT is more around what students are doing to collect the data and further what they do with the data – not the programming side of things. I understand that it is important for students to know why they are collecting the data, but I'm not sure if I'm fully there around knowing how to manipulate the micro:bit to collect different data yet.

While engaging in CT practices involves much more than simply collecting and using data, Trent appeared to be framing his current understanding of CT in terms of the computational concepts he understood the most, which can be characterized as data practices. Trent's confidence and knowledge base regarding integrating other CT practices – such as those that involve programming and algorithmic thinking – into his middle school science instruction was still developing but he was beginning to demonstrate the mindset of a science teacher who also teaches computing.

Teachers' Implementation of the Maglev Train Storyline

All five participating teachers implemented the maglev train storyline in spring 2019. In all classes, groups of approximately four students received micro:bits. The participating teachers' students ranged from fifth to eighth grade, and of the 293 students, 41% identified as female, 49% identified as male, and 10% preferred not to respond. Of these students 60% were Hispanic, 15% were White, 8% were Asian, 6% were African American, 2% were Native American, and 9% preferred not to answer.

The maglev train storyline was designed to be taught over 3 weeks, allowing multiple science concepts to be investigated. Researchers were present for teachers' launches, the first lesson using the micro:bit, and subsequent lessons that emphasized electromagnets and incorporated the micro:bit. The two focal teachers' (Trent and Carolyn) implementations and student experiences of the maglev train storyline are described next.

Trent: Implementing the Maglev Train Storyline in a Science Class

Trent implemented the maglev train storyline with his eighth-grade science class. Trent's implementation allowed his students plenty of time to engage in scientific investigations and had a strong focus on fixed magnets, which the students spent about two thirds of the unit investigating. In the other third of the unit, the students mainly investigated circuits and electromagnetism.

Trent reflected that by the end of the storyline his “students understood the concept of magnetism very well, but the aspects on electricity and circuits was a bit harder for them.” Regarding CT integration, Trent stated that programming the micro:bit to measure magnetic fields and having the students collect and analyze data “allowed my students to see something that was invisible by assigning a measurement to the magnetic field.”

Through the unit Trent highlighted both science concepts and CT practices, especially as part of an effort to encourage his students to use data to support their explanations of magnetism.

Trent commented that “student engagement was high, [and] students were asking a lot of questions right from the beginning of the unit and were eager to participate in the investigations we planned and conducted.”

This reflection was supported by Trent’s students’ survey results. A large majority of his students indicated they understood how what they did in class related to the bigger picture of what they were studying in the unit. Additionally, Trent reported that many of his students were able to engage in collaborative discussions during the investigations. On the survey the majority of his students responded that they learned more in class on a given day because other students shared ideas and opinions. A summary of Trent’s students’ survey results for the maglev train storyline is presented in Table 4.

Carolyn: Implementing the Maglev Train Storyline in a STEM Class

Carolyn implemented the maglev train storyline with her fifth-grade integrated STEM class. Unlike Trent, she did not teach this particular class of students every day; rather, she taught them for an entire week every 3 weeks. Similar to Trent, Carolyn felt confident that engaging with the sensors to investigate magnetism helped her students develop a good understanding of magnetic fields by enabling them to measure, model, and explain how magnetic fields work and interact. However, also similar to Trent, she had less confidence in the knowledge they gained about how electromagnetism works. Carolyn explained, “Students will need more time and exposure to deeply understand the concepts of magnetism as related to electricity.”

Table 4 Trent's and Carolyn's Students' Maglev Train Unit Survey Results

Survey Item	Trent's Students'[a] Experience (%)	Carolyn's Students' [b] Experience (%)
Today in class I felt like a scientist.	44.7	91.3
I understand how today's class ties to the bigger picture for what we're studying in this unit.	74.3	93
What we did in class today matters because this material is interesting to me.	37.3	63.3
I think my teacher should have us use sensors more often to conduct investigations.	82	65
I know why we did what we did in class today.	88	86
I learned more in class today because other students shared their ideas or opinions?	72.6	93.3

[a] *n* = 108
[b] *n* = 29

Carolyn was particularly successful in motivating her students to express a need to use the magnetometer on the micro:bit. She led an engaging class discussion about how tools can make the invisible visible by encouraging her students to make real life connections to concepts they were familiar with -- such as how temperature and humidity are measured and reported by weather forecasters.

Carolyn asked her students to consider the difference between saying it is warm and damp outside versus providing specific numbers to represent the temperature and humidity. Carolyn then connected this conversation to the students' investigations involving magnets, including when they used iron filings to see the shape of the magnetic field and how magnets attract and repel.

When Carolyn pressed her class to think about how they could prove what is happening with the magnets, students generated the idea of using some sort of tool to numerically measure the strength of the magnetic field. Carolyn told them, “It just so happens that these micro:bits have the ability to measure a magnetic force!” as she held up a micro:bit and pointed out the magnetometer sensor. In response her students cheered and clapped, as their thinking was validated.

Carolyn reported that her students were highly engaged throughout the storyline. This impression was supported by her students’ survey data, which showed that over 90% of students “felt like scientists” and over 65% of students indicated that the material was interesting to them. Carolyn reflected that her students engaged in collaborative discourse frequently, and the majority of her students indicated that they learned more in class on a given day because other students shared their ideas or opinions.

Carolyn focused on helping students see the Micro:bit as a tool and how to motivate the students to think about the use of the micro:bit magnetometer. A summary of Carolyn’s students’ experience data can be found in Table 4.

Teachers’ Experiences in the Implementation Reflection Workshop

After all of the teachers had taught at least some of the maglev train storyline, they came back together to share and collaboratively reflect on their implementation. The workshop began with teachers individually writing reflections about their implementation of the maglev train storyline, to trigger their memories and record their thinking.

Later in the workshop the group watched short video clips from three teachers’ maglev train lessons, highlighting particular science and engineering practices (i.e., asking questions, modeling, using mathematics and CT) that come into play when incorporating sensor technology. One of the video clips was from Carolyn’s lesson when her class first learned they could use a magnetometer to measure magnetic force. Watching this footage during the workshop, other teachers shared the strategies they used to promote students’ interest in sensors and to support their understanding of how magnetometers can be used to collect numerical data on magnetic fields. Following is a summary of the conversation that took place when teachers reflected on the ways they introduced and motivated students to use the sensors.

After viewing Carolyn’s video clip, Tracy mentioned, “We had a similar discussion about using tools to collect evidence around something invisible.” James added, “We had a discussion about putting numerical values to the magnetic field, and I had the students do an online investigation about what a magnetometer was.”

Matthew said that his students looked at videos about how ferrol fluid changes when it’s closer or farther away from magnets, which led into the idea of using sensors to measure the strength of the magnets. Trent had introduced micro:bits in a previous unit about gravity, so his students came up with using it to measure the magnets right away.

Next, the teachers viewed a video clip in which Tracy guided her students to the idea of controlling the micro:bit by speaking its language through programming using block coding. She explained, "My kids speak so many different languages, they get that a micro:bit speaks its own language." Facilitator 4 noted that this instructional strategy is called "translanguaging."

James responded, "The kids at our school have some technology background, but I don't recall how I introduced this besides having the students search about magnetometers and that I threw out the word 'coding.'" Facilitator 2, who had observed James' classes, remembered hearing some of his students say, "Oh this is just like [programming in] Scratch." Matthew stated that most of his students also had some background in Scratch, so it was a fairly easy connection. Both James and Matthew said that they tasked the students who had some prior programming experience with helping their peers.

The teachers expressed a strong desire to continue watching and discussing video clips from each other's lessons. In fact, during a planning workshop in the following year's CT-Integration Cycle, several teachers proposed using video in additional ways to support their professional learning. The proposal included watching video on their own time to see other teachers' implementations of entire lessons, filming their students' engagement in extended small group work, and reviewing relevant clips as part of the lesson planning process.

Teachers also reviewed results from the student survey during this reflection workshop, similar to the data presented in Table 2 but aggregated across all of the teachers who had given surveys. The group viewed the data, looking for patterns and considering what went well or not as well from their students' perspective.

Two main takeaways were the importance of giving students greater ownership in driving the investigations and using strategies to encourage more student participation throughout the lessons. Teachers also looked at the survey data broken down by demographic information, and they generated a variety of ideas to better support second language learners, in particular.

Toward the end of the workshop, the group reflected on the amount of sensor use and programming that took place during the maglev train storyline. Teachers were asked to react to the following two statements:

1. I think the maglev unit had the right amount of sensor use.
2. I would like more sensor use in the future.

Teachers who agreed with the first statement moved to the left side of the room and teachers who agreed with the second statement moved to the right side. James selected the left side of the room (the unit had the right amount of sensor usage). All the other teachers selected the right side (more sensor use) and began to discuss their position. James told the facilitators, "I think the maglev unit had just the right amount, but I would like to see future units have more sensor use." The teachers reorganized themselves by considering just the maglev train storyline (should it have more sensor use or did it have the right amount). Trent joined James in arguing the storyline had the right amount of sensor usage and the rest of the teachers stayed where they were. Ultimately both groups agreed that they would like to see sensors used more frequently and at a deeper level in future storyline units. However, there was a bit of split between the science and STEM teachers around focusing on the science Disciplinary Core Ideas and taking the time to use sensors more.

Next, teachers were given a different set of statements to agree or disagree with and again they moved to the corresponding side of the room.

1. Left Side: I think the maglev unit had the right amount of programming.
2. Right Side: I think the maglev train storyline needs to have students do more programming.

James and Matthew felt the storyline should have more programming while Carolyn, Tracy, and Trent felt it had the right amount. After talking briefly with her group, Tracy decided to switch groups. Trent shared, “In Matthew and Carolyn’s (STEM) classes the kids have experience programming, but in the science classes they don’t.” Carolyn agreed and argued, “It’s an intro tool for this unit, and in the future they can learn more programming.” Tracy responded, “The unit didn’t really have programming. The micro:bit was just used as a measurement tool and the coding part was heavily scaffolded. It would be good for the students to have more thought behind how to code, planning for their code, troubleshooting, and debugging their code.”

Tracy, a science teacher, reflected, “There is a lot going on in this unit - with science content, practices, micro:bits, programming. So, there’s a need to figure out what the goals are and how to find the right balance.” Matthew, a STEM teacher, responded, “My goal was to focus more on the technology, whereas the science teachers probably had more of a goal to focus on the science content.” Facilitator 2 agreed that finding the right balance is something to keep thinking about for next year and to co-design future storylines with this balance in mind.

Several teachers expressed that the hands-on activities were especially effective in engaging students, such as working with iron filings to understand magnetism as an invisible force, using the Legos to visualize and build models of levitating trains, and programming the micro:bits to measure magnetic fields. However, the teachers agreed that the students would have benefitted from additional prior experiences with the micro:bit and sensors to “showcase” what they can be used for and how they can be programmed to collect specific types of data. They also agreed that they want their students to see the value of the micro:bit in other units and investigations and become motivated to learn more about programming in the future.

Teachers' Experiences in the CT-Integration Reflection Workshop

One final workshop was held at the end of the school year to reflect on this iteration of CT-Integration Cycle and the successes and challenges teachers experienced related to the maglev train storyline, as well as to plan for the upcoming school year. Six new teachers joined the Schoolwide Labs project (Alan, Audrey, Zander and three others) and attended this workshop, which began with a review of the project and its goal of integrating CT with science.

Two returning teachers (i.e., continuing their participation in the project) each led an activity to introduce the existing storylines. Carolyn led the group through part of a storyline developed in the previous year of the project on mold growth, highlighting the unit's emphasis on helping students work with and make sense of the large data sets that can be collected using sensors. This activity prompted the teachers to think about various issues that arise when integrating CT, such as using visualizations to support students' analysis and understanding of the relevant data, as the following conversation illustrates:

> Tracy: I think playing around with data visualization would be beneficial to my students.
>
> Trent: Yes, looking at the data would allow a lot of different discussions with my students.
>
> Evan: Having a lot of data is what scientists encounter.
>
> Zander: It would be great to have a compare and contrast with the data visualizations, especially for my ELL students.

Another returning teacher, James, led the group through a portion of the maglev train storyline, highlighting programming the micro:bit to detect and measure magnetic force for students to construct models of magnetic fields. James conveyed how engaging students in the process of using sensor data to create and refine models throughout the unit helps them to develop a high-level understanding of magnetism. Both Tracy and Trent agreed that using the sensors encouraged their students to make sense of something complex that they cannot see and also supported their buy-in to the unit. The discussion related to supporting student engagement included the following exchange:

> Audrey: How do you make sure that all your students are engaged with this?
>
> James: The anchoring phenomenon and driving question board are crucial for students' ownership and are the points of reference we would go back at the end of each lesson.

> Carolyn: The driving question board that starts the unit was the buy-in for my students as well because they feel like they are driving the lesson.

During each of these activities the new teachers had many questions and wanted reassurance about how the CT-integrated storylines had worked in the returning teachers' classrooms. The enthusiasm the returning teachers displayed as they shared their successes and challenges with the new teachers clearly increased their excitement about being a part of the project and facilitating this type of learning with their students.

Teachers were introduced to additional sensors that would be available during the upcoming school year. The teachers engaged in a series of programming activities to familiarize them with these sensors and the types of data they could collect. The activities were designed to help the teachers learn new computational skills such as more complex coding, debugging, looping, and using data points as thresholds to trigger sound and different colored LEDs to activate on the micro:bit.

The returning teachers took a leadership role as they partnered with the new teachers to get them up to speed with CT and programming. For example, one returning teacher, Tracy, who had been new to sensors and programming the previous year, had grown a great deal in her both confidence and skills and eventually became a strong advocate for incorporating sensors and programming into science classes. During this workshop she mentored and encouraged some of the new teachers who had no previous experience with programming.

Teachers then discussed the feasibility and potential of a sensor immersion storyline: a week-long storyline that introduces students to sensor technology as a tool to document and display scientific phenomenon in their classrooms, such as the environmental conditions (e.g., temperature and humidity) and the amount of moisture in the soil of a class plant. They began the initial steps of codesigning this storyline by brainstorming ideas and discussing what needed to be included. The day ended with reflections and planning for the upcoming summer codesign workshops. Takeaways from this workshop included having a sense of direction for the following year, a better understanding of ways that CT can be integrated into student's science learning experiences, and a sense of developing community and excitement for the work ahead.

Discussion

Opportunities and Affordances

The goal of the NGSS is to infuse science content with practices in which students are "doing science," thus leading to instruction that is more student-driven where students can "feel like scientists" (NGSS Lead States, 2014). CT skills and practices are called for explicitly in the *Framework for K-12 Science Education* (NRC, 2012) as well as the NGSS. Science teachers typically do not have experience with CT practices and, thus, need additional support, strategies, and curriculum to help facilitate CT-integration in their science classrooms (Weintrop et al., 2016).

Integrating CT into mainstream science classes that align with the NGSS enters new conceptual and pedagogical territory for most teachers.

An effective and sustainable model of teacher learning is needed that brings teachers together to form a professional learning community to support their lesson planning, CT learning, classroom teaching, and ultimately improve student engagement and learning outcomes. To address RQ 1 our approach was to develop and study a new PD model, the CT-Integration Cycle, intended to build the capacity of science and STEM teachers to create engaging and equitable CT-integrated science learning experiences for their students.

As this article highlights, the teachers who took part in an iteration of the CT-Integration Cycle centered around the maglev train storyline engaged in a wide variety of activities intended to deepen their knowledge, use new curricular materials, and foster their students' learning and engagement. These activities included the following:

1. Learning about sensor technology and considering instructional strategies related to the use of this technology,
2. Codesigning, planning for, and analyzing lessons that all teachers implemented integrating science instruction with sensor technology,
3. Developing a better understanding NGSS-aligned science instruction through watching and discussing video clips,
4. Considering a variety of CT practices and how to effectively integrate them into science classrooms, and
5. Actively monitoring student interest, engagement, and equity in the design and implementation of CT integrated science lessons.

Clearly these activities represent a myriad of goals and require ongoing and in-depth professional learning efforts. Our intention in this article is to highlight that such goals can be aligned in a purposeful manner and to illustrate how this alignment looked as part of a specific PD model. The focus of the maglev train iteration of the CT-Integration Cycle was squarely on pedagogy, with an additional emphasis on co-design, NGSS, and CT. Throughout this process, teachers were continually engaged in thinking about teaching while they also worked to develop, implement, and reflect on storylines that integrated both science and CT.

Teachers Experiences and Participation

The CT-Integration Cycle served to provide structures and processes through which the teachers were able to collaboratively experience and develop a shared understanding of CT practices and CT-integration with science (Grover & Pea, 2013; Mason et al., 2019), resulting in their students using programmable sensors to investigate scientific phenomena through NGSS-aligned CT integrated storylines (Gendreau Chakarov et al., 2019b). Our findings regarding RQ 2 suggest the CT-integration cycle provided numerous opportunities for teachers to learn through codesigning, implementing, and reflecting on how science and CT can complement each other in curriculum and instruction.

We acknowledge that this project worked with only five teachers and as such these findings may not be generalizable to other contexts. However, lessons learned from this project can be adapted and used for similar investigations involving CT integration and PD.

Engaging teachers to take an active role in codesigning storylines (Reiser, 2014) based around scientific phenomena has proven to be a successful vehicle for moving toward CT-integration (Jona et al., 2014; Voogt et al., 2015) and implementing the NGSS in ways congruent with the *Framework for K-12 Science Education's* (NRC, 2012) intentions. As they took part in shaping the storyline, teachers in the Schoolwide Labs project thought carefully about questions their students were likely to have, how to intentionally incorporate sensors and CT, what resources would be needed to support their students' learning, and how to ensure the storyline fit with their curricular goals. Overall, the codesigning and planning experiences provided the teachers with a sense of ownership and voice in the maglev train storyline and increased their buy-in to the project and the goal of integrating CT with science.

One ongoing challenge is learning how to recognize whether a storyline or lesson is "CT-integrated" (McGinnis et al., 2020). Our research team learned several lessons from conducting this iteration of CT-Integration Cycle, especially around the design of PD activities that support teachers to incorporate CT in their classrooms with increasing confidence and frequency. The most effective PD activities provided clarity about what CT-integration into science instruction looks like and how to balance time spent on science versus CT so that students' science learning is enhanced. As a research team we are seeking to be more intentional in helping teachers conceptualize CT as reaching beyond the use of computational tools for data collection and analysis and as a general strategy for computational problem solving that includes an array of practices.

CT was a new concept for the science teachers and some of the pedagogy and content around teaching science was new for integrated STEM teachers. As such, all of the teachers struggled to some degree to integrate CT and science. This struggle can be seen in Trent's experience when he had a difficult time learning programming and understanding the differences between CT and traditional "problem solving" (McGinnis et al., 2020).

Although at present we lack quantitative data regarding the effectiveness of participating in the CT-Integration Cycle, anecdotal evidence suggests that the teachers increased their knowledge and skills related to CT, particularly in terms of collecting and analyzing big data streams, understanding what these CT practices look like, and recognizing the benefits of incorporating them into science instruction. We have also seen shifts in the teachers' comfort and knowledge around facilitating CT-integration with middle schoolers. For example, most teachers started the project effectively supporting their students to collect data using sensors, but then reverting to traditional (noncomputational) methods to organize and analyze data. The participating teachers moved beyond this basic level to engaging their students in programming sensors to collect targeted data in planned and thoughtful ways, problem solving and debugging during programming, and beginning to utilize more complex CT skills, like preparing for long-term data collection, and using data to set thresholds to trigger actions, such as sounding audible tones or lighting LEDs.

Conclusion

As computer science and CT have become increasingly ubiquitous in the 21st century, there is a need for K12 education to adopt activities that expose students to these concepts throughout the curriculum (Barr & Stephenson, 2011; NRC, 2012; NGSS Lead States, 2013; Yadav et al., 2016). This need has led to the development of specific computer science classes, after school activities (Kick & Trees, 2015; Repenning et al., 2010), and curriculum to integrate CT in mainstream math (Schanzer et al., 2015) and science classes (Basu et al., 2016; Denning et al., 2017).

CT-integration in science classes has most often involved the creation and use of computational models and simulations (Sengupta et al., 2013). Many of these efforts have focused more on providing curriculum for teachers and less on developing their capacity to understand the nuances of CT-integration into their discipline. In this paper, we highlighted a professional learning model and an instantiated cycle that can be used to promote the design of computationally rich science curriculum and enhance teachers' capacity to implement such curricula. Several other research studies focusing on developing teacher capacity around computer science are in their early phases (Dettori et al., 2016; Jacob et al., 2019; Lee et al., 2017). As CT continues to permeate the K-12 curriculum, there is a need to continue the development of professional learning models that increase teacher capacity around CT and showcase the affordances of CT-integration for students.

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Appendix

Teacher workshop reflection questions, asked across multiple workshops:

- What are you thinking and wondering about related to collaborative design of science+CT curriculum?
- How do you see CT represented in the micro:bit exercises you completed?
- What questions do you have about what CT looks like when integrated into middle school science?
- Has taking part in this project influenced how you view CT?
- What questions do you have about CT?
- What additional supports would help you to implement CT-integrated instruction using micro:bits?
- How, if at all, has co-design helped you learn and grow as a science or STEM teacher?
- What are your overall thoughts about the MagLev storyline?
- What part(s) of the maglev train storyline are you most confident about implementing?
- What are your reflections on your experience with the maglev unit in the classroom?
- How well do you think students learned science content in terms of the storyline?
- What about the unit about the unit was most engaging to your students?
- In what ways did the sensors enhance/take away from students' science learning?
- What issues did you run into using the micro:bit?

Focus group interview questions, asked across multiple interviews:

- Why did you get involved in this project? What seems exciting to you about this project?
- What do you hope to do and learn over the course of the year?
- What do you hope your students will do and learn over the course of the year?
- What three adjectives would you use to describe this project?
- To what extent do you feel your expertise has been heard in the process of co-designing the storyline?
- How much structure and support do you expect to need for implementing the maglev train storyline?
- How, if at all, has your participation in this project influenced how you feel about your role as a teacher?
- What aspects of the project did you especially like and which ones could be improved?
- How do you feel about the support you've received from the research team outside of the PD sessions?
- With your participation in this project (learning about storylining and sensor technology), what are differences in how you plan and teach in your classroom this year as compared to last year?

- Which parts of this project feel most worth your time and why?
- In implementing the maglev unit, how supported did you feel by the research team?
- Did you work with or get support from other teachers in this project?
- If you were to recommend participating in a project like this to your fellow teachers, what would you say?
- What have you learned so far from participating in this project?
- What seems exciting to you about continuing in this project?
- What questions or concerns do you have moving forward?

Maglev train storyline implementation debrief questions:

- How did you think the maglev unit went as a whole?
- What did your students learn from the unit?
- Are there things you would do differently if you were to teach it again?
- How much did you rely on the storyline/teacher guide when planning for & implementing the maglev storyline?
- What supports included with the storyline were most useful?
- How engaged were your students in the unit compared to how engaged they usually are?
- What elements of the unit supported student engagement?
- Did the unit sustain your students' interest throughout?
- Were there parts that were less student driven than you expected?
- How did you feel about the use of sensors in the unit? Were there surprises or challenges?
- Did focusing on CT practices add value to your students' science learning in the unit?
- What have you learned from using this unit that will help you in teaching future concepts using 3D Learning and/or CT practices?