Integrating Computational Thinking into Middle School Science through Co-designed Storylines

Quentin Biddy
Alexandra Gendreu Chakarov
Jennifer Jacobs
Tamara Sumner
Mimi Recker
William Penuel

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Proceedings Abstract: We describe a professional development model that supports teachers to integrate computational thinking (CT) and computer science principles into middle school science and STEM classes. The model includes the collaborative design (co-design) (Voogt et al., 2015) of storylines or curricular units aligned with the Next Generation Science Standards (NGSS Lead States, 2013) that utilize programmable sensors such as those contained on the micro:bit. Teachers spend several workshops co-designing CT-integrated storylines and preparing to implement them with their own students. As part of this process, teachers develop or modify curricular materials to ensure a focus on coherent, student driven instruction through the investigation of scientific phenomena that are relevant to the students and utilize sensor technology. Teachers implement the storylines and meet to collaboratively reflect on their instructional practices as well as their students' learning. Throughout this cyclical, multi-year process, teachers develop expertise in CT-integrated science instruction as they plan for and use instructional practices that align with three dimension science teaching and foreground computational thinking. Throughout the professional learning process, teachers alternate between wearing their "student hats" and their "teacher hats", in order to maintain both a student and teacher perspective as they co-design and reflect on their implementation of CT-integrated units. This paper illustrates two teachers' experiences of the professional development process over a two-year period, including their learning, planning, implementation, and reflection on two co-designed units.

Body:

Modern science and engineering are increasingly utilizing computational tools to program sensors and other instruments to collect, analyze, and visualize streams of data to develop models to explain phenomena and create solutions for problems (Foster, 2006). Yet in many K-12 classrooms computing has often been isolated in separate, elective classes and after school clubs, leading to inequities in opportunities for students to learn computational thinking skills (Margolis et al., 2008). Despite this, engaging students in Computational Thinking (CT) and CT practices (Weintrop et al., 2016) in a 3-D Learning context can help students “develop an understanding of the enterprise of science as a whole—the wondering, investigating, questioning, data collecting and analyzing” (NGSS Lead States Appendix H, p. 1). Compelling arguments exist for integrating CT into mainstream science and mathematics classes to provide an engaging and realistic context for the development of authentic CT skills and practices as well as to promote all students’ ability to engage in challenging scientific inquiry (Sengupta et al., 2013; Sherin, diSessa & Hammer, 1993).

Additionally, as more science classrooms are transitioning to standards based on the three dimensions outlined in *A Framework for K-12 Science Education* (NRC, 2012), more students are engaging in 3D-Learning (Krajick, 2015) that engages students in practicing science and engineering in a way that mirrors how scientists and engineers work. One central goal of science education is for students to become “scientifically literate citizens” who understand the basic nature of science (NGSS Lead States, 2013). Additionally the two goals set forth by the National Research Council in *A Framework for K-12 Science Education* (2012, p. 10) include: “(1) educating all students in science and engineering and (2) providing the foundational knowledge for those who will become the scientists, engineers, technologists, and technicians of the future.” In this context it is important for science teachers to have the tools and resources to successfully integrate CT into science instruction. An important missing piece is the design of curricular units that engage students in specific computational and data practices while developing their interest in this fundamental aspect of contemporary scientific inquiry.

In order to implement computational thinking into the K-12 curriculum, the definition of CT must be detailed enough so teachers and curriculum developers understand how to create and implement lessons and assess student understanding (Grover & Pea, 2013). Based on a synthesis of research, Weintrop et al. (2016) distilled four categories of CT practices in science: data practices, modeling and simulation practices, computational problem-solving practices, and systems thinking practices. Weintrop and colleagues’ categories of practice can help the education community develop a common language of this relatively elusive construct, move towards the focused development of CT-integrated curriculum, and ultimately lead to science instruction that deeply and purposely incorporates CT.

Integrating CT into mainstream science classes that align with the NGSS is a highly demanding endeavor, which enters new conceptual and pedagogical territory for most teachers. An effective and sustainable model of professional development (PD) is needed that brings teachers together to form a professional learning community, with the goals of supporting their lesson planning, CT learning, classroom teaching, and ultimately improving student engagement and learning outcomes. Our approach is to develop and study a new PD model, called the CT-Integration Cycle, intended to build science and STEM teacher capacity to create engaging and equitable student CT-integrated science learning experiences.

In this paper we will discuss strategies, tools, and resources developed in a project funded by the National Science Foundation (NSF Awards 1742046 and 1742053). SchoolWide

Labs is a three-year research and practice partnership project focused on integrating CT into middle school science in a way that complements and enhances students' science learning designed to answer these four research questions:

1. In what ways, and for which student populations, do the SchoolWide Labs learning experiences deepen interest and engagement in CT?

2. Which learning experiences are most effective at deepening students' disciplinary science knowledge?

3. To what degree and in what ways do teachers' planned and enacted sensor-based lessons change over time? Are there differences across teachers and science content areas?

4. What professional learning processes and tools support teachers to productively integrate CT using a sensing platform into their disciplinary STEM instruction?

This is accomplished by providing yearlong professional development and support to middle school teachers in the partnering school district through a longstanding research practice partnership. One important aspect of this work includes working collaboratively with practicing science teachers to co-design storylines (Reiser, Novak, and Fumagalli, 2015; Reiser et. al., 2016) that integrate CT practices and sensors.

In collaboration with the partnering district, our research team generated a set of design constraints that guided both our PD model and the CT-integrated units that the participating teachers helped to design and implement. Focusing on these issues ensured our work was situated within the current literature on both science and CT, as well as best practices for classroom instruction to support the learning of diverse students. The focal issues were to (1) deeply integrate multiple CT practices into mainstream science lessons, (2) incorporate performance expectations, science and engineering practices, and cross-cutting concepts as defined in the Next Generation Science Standards, (3) ensure that lessons are engaging, interesting, and relevant to students, (4) include place-based or locally relevant scientific investigations and activities, and (5) use a sensor platform to conduct data driven explorations of scientific phenomenon.

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." One strategy that has proven successful for ensuring that the NGSS are implemented in the intended manner is to develop storylines (Reiser, 2014) based around scientific phenomena (NGSS Lead States, 2016), such as how the moon affects tides. Storylines serve as unit guides and are generated before writing individual lessons to ensure coherence and incremental knowledge building (Reiser, 2014; Penuel & Reiser, 2018). Of critical importance is selecting a scientific phenomenon that "anchors" the storyline to issues that are locally relevant and interesting for students, much as a driving question in project-based learning ensures student motivation and promotes deeper levels of thinking (see Blumenfeld et al., 1991)

In addition, research suggests that place-based investigations can offer a powerful tool for engaging learners from underrepresented groups in STEM (Anastopoulou et al., 2012). Place-based investigations focus on personally or locally relevant phenomena or activities that address issues meaningful to the local community. As such, students are able to consider such questions as “why here?” and “so what?” that provide a relevant, meaningful context for the phenomenon they are learning about (Buxton, 2010).

Finally, one novel way to conduct scientific investigations is through a low cost, mobile sensor platform that provides an entry point for teachers to go beyond traditional data analysis of either small, curated data sets or large, pre-existing data sets that students simply download from the Web. Sensor platforms have the potential to support several of the CT practices defined by Weintrop and colleagues (2016). For example, sensors can collect real-time environmental streams of data, such as heat, temperature, light, sound, etc. Also, a sensor platform can be programmed to collect, filter, analyze and display students’ data.

The project follows three high-level theoretically principled conjectures to guide the research and development process: 1) Learning experiences that utilize the sensing platform to investigate phenomena relevant to students' lives will engage diverse learners in CT, 2) learning experiences that deeply integrate CT practices and science and engineering practices will support students to develop robust CT skills, competencies, and dispositions as well as deepen their understanding of STEM subjects, and 3) the CT Integration Cycle can support teachers to productively integrate CT into their STEM instructional planning and classroom implementation.

Through this study the sensing technology is integrated into a series of lessons that address identified performance expectations in the Next Generation Science Standards (NGSS) as well as science and engineering practices and CT practices. Each instructional unit is referred to as a storyline -- a set of lessons that are driven by student questions about a specific scientific phenomena and/or design challenge. These storylines use students’ questions and ideas to ground the sensing investigation and drive the class forward.

Yearlong teacher professional development (PD) workshops based on a structure we have labelled the “CT Integration Cycle” were provided to participating teachers. This PD structure reflects best practices defined in the current research literature and our prior experiences developing and implementing the Problem-Solving Cycle. CT Integration Cycle workshops take place during the summer as well as during regularly scheduled intervals throughout the school year. Activities that take place during the workshops include learning about sensor technology, researchers and teachers co-designing storylines that integrate sensor technology, preparing to implement the storylines, sharing and discussing videoclips from the teachers’ classroom implementations of the storylines, and considering revisions to the storylines and the use of sensor technology.

Throughout the PD workshops, teachers engage in the following activities: 1) learn about and practice using each component of the sensor platform, and consider instructional strategies related to the use of the sensors, 2) engage in activities related to improving NGSS-aligned science instruction, 3) examine a variety of CT practices and consider how to effectively integrate them into science classrooms, 3) co-design, plan for, and analyze lessons that all teachers implement integrating science instruction with sensor technology, and 4) actively consider student interest, engagement, and equity in the design and implementation of CT integrated science lessons

This paper will describe the PD strategies and activities involved in the “CT-Integration Cycle” as well as address the following objectives:

1. Understanding of how CT can be integrated into science curriculum and instruction.
2. Understanding of how to utilize anchoring phenomena and driving questions boards to generate and identify questions that can be investigated through CT integration and programmable sensors.
3. Understanding of how to utilize simple block coding to program a user-friendly sensing platform to collect, analyze and visualize data to answer questions and explain phenomena.

The CT-Integration Cycle (see Figure 1) is a professional development approach to help build teacher capacity to implement CT-integrated instructional storylines activities. The CT-Integration Cycle provides a structure and process for teachers to learn about CT, new computing technologies, and their integration into NGSS-aligned science classrooms (Chakarov et al., 2019). Teachers participate in a connected series PD workshops that involve learning, planning, implementation, and reflective activities with peers (Kazemi & Hubbard, 2008). The CT-Integration Cycle combines aspects of the Problem-Solving Cycle model of mathematics professional development (Borko et al. 2015) with elements of science curriculum co-design workshops (Severance, Penuel, Leary, & Sumner, 2016).

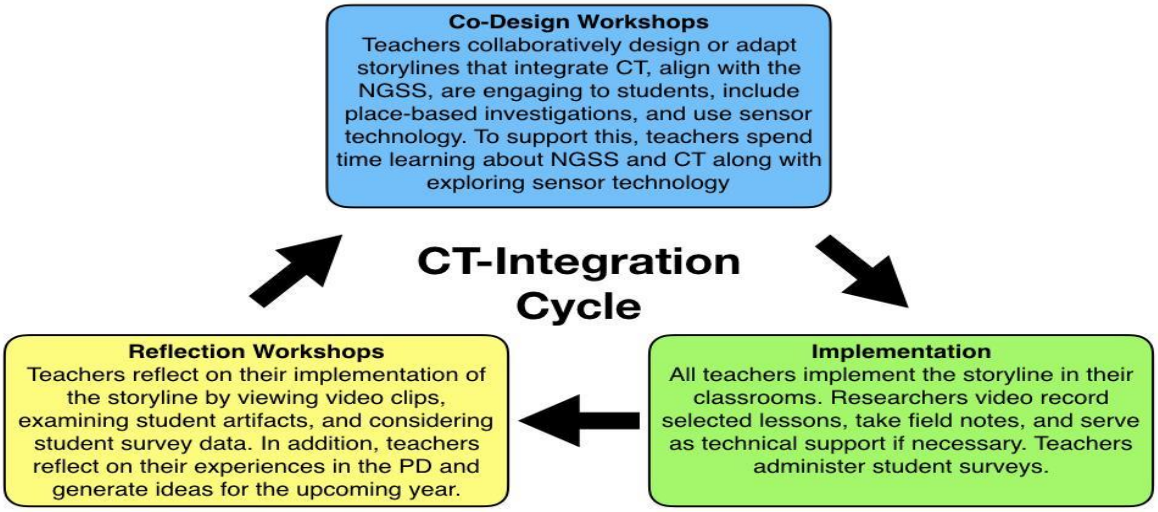

Figure 1: The CT-Integration Cycle

The CT-Integration Cycle consists of three phases: Co-Design, Implementation, Reflection. It involves collaborative lesson planning and uses video from teachers' implementation of lessons as a vehicle for targeted reflection. To focus the reflection process researchers can choose specific lessons in the storyline to video record that they expect might contain particularly interesting teacher moves and potentially include productive student interactions. These lessons generally include the beginning of the unit, students' use of the sensor platform, and the conclusion of the unit.

During the co-design workshops, teachers and researchers work together to create and modify science curriculum. Building on the storylining approach (Reiser, 2014), the group develops NGSS-aligned instructional units in which students employ CT as they make sense of scientific phenomena using a sensor platform. Teachers play a central role in developing the units in an effort to increase their own learning, ensure students' engagement and interest in the curriculum, and consider the feasibility and appropriateness of the units for their local classroom context (Severance, et.al, 2016). In addition, the design phase includes opportunities for the teachers to engage in CT activities by playing the role of students, both to gain new knowledge and to better appreciate the student perspective.

An important part of the co-design process involves determining and "unpacking" the science content that will be included in the unit. Unpacking includes identifying the performance expectations (PEs) from the NGSS that students will engage with and deconstructing the language of the PEs to determine how they should look in the classroom. Additionally, teachers ensure there is a match between the PEs, the scientific phenomenon they plan to investigate, the targeted CT practices, and the capabilities of the sensor platform.

After implementation, the set of focal issues that guided both our PD model and the CT-integrated units serve as guidelines for reflection activities. In other words, teachers consider how well their storyline implementation went with respect to each focal issue (CT practices, NGSS alignment, student engagement, place-based, and use of a sensor platform). Teachers view selected video clips that highlight interesting or unique aspects of their implementation. Teachers also share and discuss student artifacts, such as written models or explanations constructed by their students. Additionally, teachers consider aggregated student survey data collected throughout the storyline implementation, as a vehicle to reflect on their students' interest and engagement in the storyline.

To wrap up the yearlong CT-Integration Cycle, teachers reflect on their experiences and discuss what they would like to improve on during the next cycle. Typically, teachers spend a good deal of time planning for upcoming workshops, including considering candidate phenomenon for new storylines, whether and how to incorporate additional sensors, and ways to attend more carefully to the integration of CT practices. Teachers also reflect on how their views and understanding of computational thinking have evolved over the course of the year, how the sensor platform has influenced their science instruction, and how they can better foster their students' learning and engagement in CT-integrated science classes.

During this paper presentation one iteration of the CT-Integration Cycle and the preliminary findings will be outlined within the context of the second year of the project in which the participating teachers were able to develop a strong understanding of CT practices, test the usability of a robust sensing platform, and build capacity to co-design CT-integrated NGSS-aligned storylines. Five middle school teachers participated; two had participated in iteration one and three were new to the project. A collaborative approach was used to create the storyline, which largely drew on two NGSS performance expectations about understanding invisible fields between objects, such as magnetic and gravitational fields. Trains powered by magnetic levitation, called maglev trains, served as the anchoring phenomenon to drive students' questions and investigations (see Figure 2).

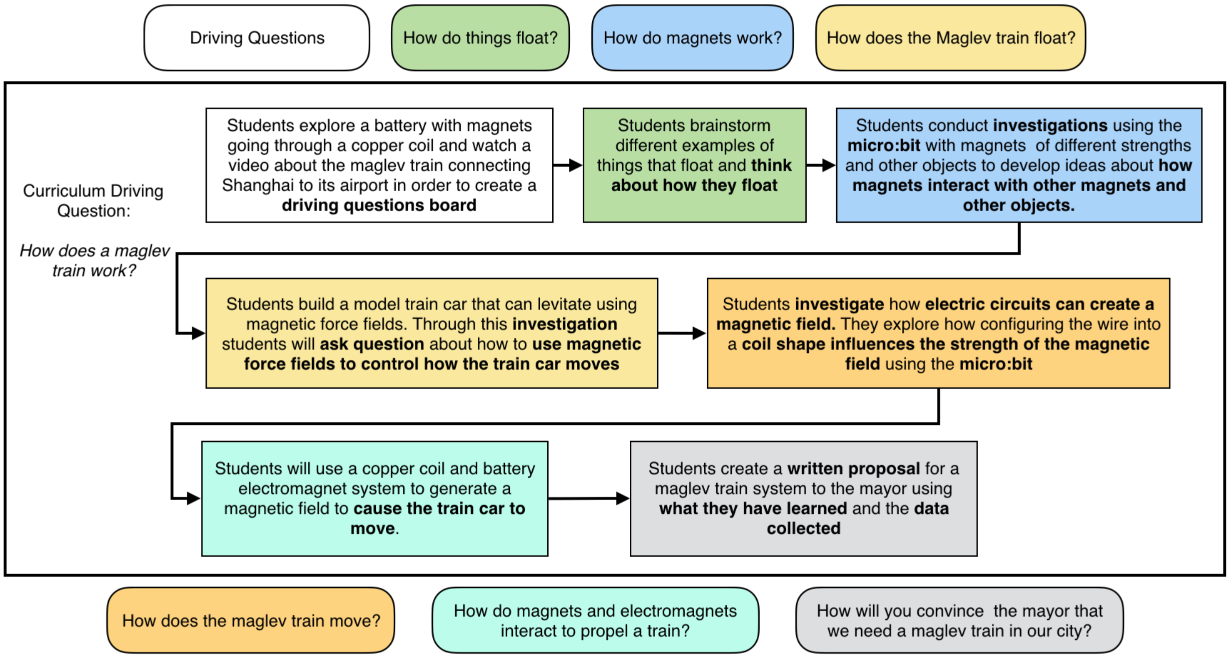

Figure 2. The maglev train storyline addresses the question: How does a maglev train work? The bold text in the graphic refers to the science content and science and CT Practices.

The maglev train storyline was designed to be implemented over three full weeks of classroom instruction allowing a larger number of science concepts to be investigated at a deeper level. The focus on place, or a location relevant to students, was not as foregrounded, but the unit did include connections to traffic problems experienced by the local community that might be mitigated by high speed maglev and concluded with students writing a proposal to the mayor about the ideal location for a maglev train in their city.

Developing an understanding of how CT and CT practices could be integrated into science classes and how to support such integration could be valuable knowledge for practicing teachers, administrators, curriculum coordinators and teacher educators, both pre-service and in-service. Students are entering a world in which CT is increasingly necessary for success in both science and engineering careers as well as careers outside those fields. Teachers today must prepare their students for the jobs of tomorrow that have yet to exist. Integrating CT into science in a meaningful way that enhances students' science investigations can be one way to achieve this goal. Science teachers at all levels as well as those that support these teachers can benefit from understanding ways in which CT can be integrated successfully into mainstream science classes.

Computational thinking skills and practices are called for explicitly in the *Framework* (NRC, 2012) and in the *NGSS* (NGSS Lead States, 2014). Many science teachers may not have experience with computational thinking practices and need additional support, strategies, and curriculum to help facilitate CT integration into their science classrooms (Weintrop, et, al, 2016). This workshop will include activities such as examining a CT integrated science curriculum, utilizing an anchoring phenomena routine and driving question board to elicit students questions that can be investigated using CT and sensors, using sensors and block based programming to code sensors to collect and analyze relevant data, and strategies to engage students in investigations using CT practices and sensors. This workshop is primarily directed toward science teachers seeking to integrate CT into their mainstream science classrooms and in-service science teacher educators and curriculum coordinators and developers supporting teachers as they learn to integrate CT into science instruction such as. Science education methods instructors may find this information valuable as they prepare preservice teachers to enter the science teaching field where CT integrated science instruction will be more commonplace. Additionally, informal science educators may find value in understanding CT integration in science education as they engage students in meaningful learning experiences in novel settings where CT could reinforce connections between what they do and the NGSS.

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