Integrating Computational Thinking into Middle School Science Curriculum Using Programmable Sensor Technologies

by

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With the increasing ubiquity of computing in the world, there has been a push to increase the number of experiences K-12 students have with computer science and computational thinking. Strategies to achieve this include out of school programs, computer science and STEM specific courses, and the integration of the computational thinking into other subject areas. Science is one such subject area as it is a field that is increasingly relying on computational methods and tools. A goal of science education is to give students experiences that closely mimic real scientists' work.

SchoolWide Labs is an approach to integrating computational thinking into science classes using programmable sensor technologies. Students use the sensors to explore and gather information about the world around them–much like real scientists–and engage in CT to make sense of scientific phenomena. SchoolWide Labs involves creating programmable sensor technologies, professional development workshops to support teachers' implementation of units integrated with computational thinking, and tools for professional development workshops and classroom implementation. This dissertation describes the evolution of computational thinking and programmable sensor technologies in the SchoolWide Labs project over three year-long design cycles. This dissertation highlights lessons learned from the first two design cycles and discusses how they influenced significant changes to the third design cycle with the development of an introductory sensor immersion experience and a change in the integration of computational thinking is integrated.

Dedication

To Aleks, Mitko, and Rila

Acknowledgements

First off, I would like to thank my committee and especially my advisor, Tamara Sumner, for the breadth of knowledge they provided me in computer science, learning sciences, and education. Next, none of this would have been possible without the SchoolWide Labs Team. I am grateful for the teachers from Denver Public Schools for allowing me into their classrooms and always being willing to try new things. Also, I need to thank Jennifer Jacobs and Quentin Biddy for providing a sounding board for my ideas and writing and just generally being amazing colleagues.

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Contents

Chapter

Appendix

Tables

Table

Figures

Figure

Chapter 1

Introduction

There is a growing body of literature that recognizes the importance of broadening participation among underrepresented groups in Science, Technology, Engineering, and Mathematics (STEM) by the government, the private sector, as well as academia in the United States [86], with the issue of computer science and computational thinking being especially important [98, 97]. Access is a significant issue that affects participation in STEM activities. To increase participation, students must have access to courses and experiences in STEM subjects. Ideally, these experiences will be engaging and relevant to maintain student interest and encourage them to pursue other STEM opportunities.

Computational thinking has become one of the most discussed and mysterious phrases in K-12 STEM education and computer science. It first gained popularity in the 2006 ACM article by Jeannette Wing [166], in which she advocates for computational thinking for all. She describes computational thinking as a necessity for all subjects and wants to include it with three R's: reading, writing, and arithmetic as an integral part of the K-12 curriculum [166]. She defines computational thinking as solving problems, designing systems, and understanding human behavior by utilizing fundamental computer science concepts [166]. When it comes to implementing computational thinking activities in the classroom, her definition is too high level and vague to easily translate into curriculum. Numerous educators and researchers have attempted to give specificity to Wing's definition of computational thinking in order to design activities in computer science and other STEM programs that promote the acquisition of computational thinking skills [57, 159, 128, 91].

Over the last ten years, educators and researchers have employed a wide variety of strategies to increase access to computational thinking experiences. After school programs and hour of code activities have popped up around the country to expose students in general and underrepresented groups to computational thinking activities [34]. There has been a push to add computer science courses and adopt computer science standards with specific computational thinking components [30]. In addition, research has explored integrating computational thinking into the existing science and mathematics curricula [131, 69, 87, 32] with computational thinking being explicitly called out in the Next Generation Science Standards (NGSS)[87]. Integrating computational thinking into math and science classes that are part of the required K-12 curriculum provides an opportunity to engage all students in computational thinking activities thus avoiding the pitfall of the opting-in phenomenon since many computer science and engineering classes that focus more specifically on computational thinking are electives.

Outside of the classroom, these disciplines are increasingly relying on computational tools and methods [44, 5]. Science classes provide an exceptionally rich space for integration, given the emphasis on inquiry-based instructional approaches designed to make classroom scientific investigations closer to the work of real scientists [87, 108, 126].

However, a critical gap remains in understanding how to best integrate computational thinking into science instruction beyond merely including bigger datasets or adding technological instruments. Instead, the goal is to provide students with ongoing experiences to advance their computational thinking skills and support their understanding of how those skills are a fundamental aspect of contemporary scientific inquiry.

One promising approach is through the use of small, mobile sensors [14, 105, 43]. Sensors have a long history of supporting the learning of computer science and computational thinking through tools such as LEGO Mindstorms^{TM} and other robotics [91, 129]. As these sensors become increasingly low-cost and widely available, they are more accessible to teachers for classroom use. They can be instrumented to provide fine-grained and continuous measurements of the physical world (e.g., temperature, magnetism) in order to explore scientific phenomena such as air quality [165] or information about the local watershed [96].

Moreover, research suggests that focusing on phenomena that are grounded in students' *place* (for example, schools and local communities) can offer a powerful tool for engaging learners from underrepresented groups in STEM [120, 4, 154, 77]. Place-based investigations focus on personally relevant scientific phenomena or activities that address issues meaningful to the local community. Sensor technologies support these investigations through the collection of meaningful local data related to the phenomenon. Students consider *why here?* and *so what?* questions that provide local context for the phenomenon they are learning about [22].

One challenge with integrating computational thinking experiences into science classes is that science teachers have little to no training in using computational tools and supporting their students to develop computational thinking skills [91, 90]. To move beyond boutique computational thinking experiences that rely on extensive researcher support, teachers need curricula and tools that easily supports integration and professional development experiences to prepare them to implement computationally rich lessons.

To address this area of need in the community, SchoolWide Labs aims to integrate Computational Thinking into required middle school science and integrated STEM classes in Denver Public Schools through the use of sensors to support place-based investigations. Since these classes are mandatory, **all** students receive some exposure to computational thinking. In collaboration with district partners, teachers, and SparkFun Electronics, we collaboratively design (co-design) and implement science units that integrate computational thinking. This process includes the development of three products: 1) novel sensor technologies suited for use by middle school students, 2) toolkits to support teachers in implementing the units in their classrooms without extensive researcher support, and 3) a professional development model to aid teachers in developing the skills necessary to implement the units in a meaningful, student-driven manner that aligns with the current best practices in science education.

This dissertation is organized as follows: Chapter 2 outlines relevant prior research and related work in computational thinking, sensor technologies, science education, and place-based education. Chapter 3 discusses the SchoolWide Labs project as a whole and describes the specific contributions of this dissertation around the integration of computational thinking and sensor technologies. Chapter 4 highlights the lessons learned around the integration of computational thinking and sensor technologies from the first two years of the project and identifies how these lessons learned influence the third year of the project. Chapter 5 describes the design and implementation of a sensor immersion experience during the third year of the project. Chapter 6 details the development of a new description of what computational thinking looks like in science classes. Chapter 7 synthesizes the major themes from the previous three chapters and provides ideas about how the SchoolWide Labs project will progress in the short term. Chapter 8 concludes this dissertation with a step back to look at the broader scope of computational thinking and computer science education and some ideas about its future directions.

Chapter 2

Relevant Prior Research

This chapter discusses four threads of research that serve as the basis for this dissertation. It begins with a discussion on the prior work in Computational Thinking, including how specific frameworks and strategies promote the integration of computational thinking into science classes. It continues with a discussion on how sensor technologies, which are becoming increasingly affordable, can be used in the K-12 classroom. Since this dissertation works towards integrating Computational Thinking into mainstream middle school science classes, it draws on current best practices in science education. This literature provides instructional design techniques and helps ground the integration of computational thinking in state of the art science curriculum. Lastly, an affordance given by adopting the programmable sensor technology into science class is that students can collect data from their place, situating their learning in relation to their school and community. The goal of this chapter is to provide the reader with sufficient background information on each area. Chapter 3 addresses how these topics are incorporated specifically into this dissertation.

2.1 Computational Thinking

In order to implement computational thinking into the K-12 curriculum, the definition must be detailed enough so teachers and curriculum developers understand how to implement specific lessons and assess student performance and understanding [8, 57]. The details must also correspond to the specific subjects that teach computational thinking, whether in a computer science class, math class, or science class. By including computational thinking skills in required science and

STEM classes, more students are exposed to and develop skills in elements of computer science and computational thinking. However, this presents an additional challenge: expecting teachers with little computing background to make computational thinking an integral part of their classrooms. In order to do this, frameworks for understanding and recognizing computational thinking need to be developed.

2.1.1 Computational Thinking Frameworks

Brennan and Resnick Framework. One popular framework for examining students' uptake of computational thinking describes three distinct dimensions of computational thinking: *concepts*, *practices*, and *perspectives* [18]. These dimensions are defined based on extensive data collection in the form of programming artifacts from Scratch[1] projects as well as interviews with youth.

Computational thinking *concepts* are a set of ideas that have to do with the construction of a computer program [18]. Computational thinking *practices* describe the processes of assembling the basic building blocks of computational thinking concepts. The latter "focus on the process of thinking and learning, moving beyond *what* you are learning to *how* you are learning" [18]. These practices represent some of the different strategies employed when thinking computationally.

Brennan and Resnick [18] observed that students exhibited behaviors not captured by either the computational concepts or computational practices. The students described "evolving understanding of themselves, their relationships to others, and the technological world around them". These new *perspectives* brought on by interactions with computational tools are *expressing*, *connecting*, and *questioning*. In the *expressing perspective*, students see themselves as creators and computational tools as a means to illustrate these creations. This medium provides increased opportunities for both self-expression and expression in front of a wider audience. *Connecting* involves seeing the value in "creating with others" and "creating for others" [18]. Computational tools are a new medium for connecting and spreading information, leading to questions about the information and technology. The students are empowered to *ask questions* about the computational tools they

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[1] https://scratch.mit.edu/

are using, the information they discover, and some deeper technological concepts. Students should be empowered to ask questions with and about technology.

The *Perspectives Practices* [18] take STEM learning from using computers as a tool to enhance content already present in the curriculum to generating new content. They support students using new mediums to explore and relate to the problems they are solving, whether that be connecting with a student across the country, expressing their solution in a unique visualization, or questioning what the solution means for the world. In the words of Roy Pea [31], "Connecting computational thinking in personally meaningful ways is at the heart of tackling the problem how everyone can be brought into a pathway for developing and using computational thinking in their everyday lives." Bringing everyone into the computational thinking world is one of the ultimate goals of this dissertation.

The Brennan and Resnick framework has proven useful for examining students' computational thinking skills in programming and computer science related projects [136, 76]. However, this framework is most useful for analyzing students' programs and activities specific to computer science classes. A framework for integrating computational thinking into science needs to go beyond programming and connect to areas of particular import to science, such as modeling and data analysis.

Computational Thinking in All Subjects. Barr and Stephenson [8] introduce a framework describing computational thinking in all the subjects designed to address Wing's [166] original mission of seeing computational thinking present across disciplines. They created a set of computational thinking concepts with examples of how to integrate them into computer science, math, science, social studies, and language arts. The examples they describe are activities that students are already doing in these classes just thought of through a computational lens. For example, students can use abstraction in science class to build a scientific model or algorithms and procedures to design and conduct an experiment or investigation. Of note is that integrating computational thinking into these subjects does not require the use of computational tools merely reframing and explicitly calling out activities students are already doing.

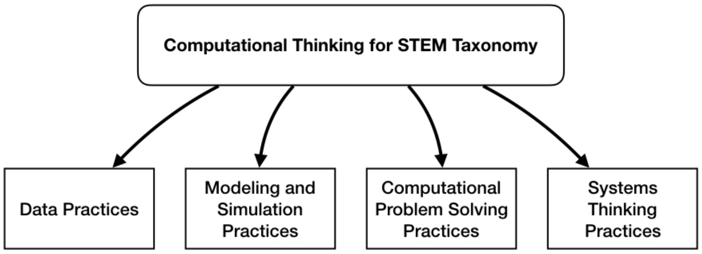

Figure 2.1: Computational Thinking in Mathematics and Science taxonomy [159].

While general frameworks help build an understanding of computational thinking across disciplines and connections between disciplines, they lack enough details for individual subject teachers to use them as their only tool for integration. Teachers and curriculum developers need frameworks specific to their instantiation of what computational thinking looks like in their discipline to support deep integration of computational thinking throughout the curriculum.

Computational Thinking in Mathematics and Science Taxonomy. Weintrop and colleagues [159] created the Computational Thinking in Mathematics and Science Taxonomy to explicitly define what computational thinking looked like in K-12 mathematics and science classes. They utilized an iterative design based on a literature review and current computational thinking infused lessons. One key element of their research strategy is to collaborate with STEM professionals and K-12 STEM teachers to understand better what computational thinking looks like in STEM.

Through this process, they develop four significant categories of computational thinking they referred to as practices: *Data Practices*, *Modeling and Simulation Practices*, *Computational Problem Solving Practices*, and *Systems Thinking Practices*. They referred the categories as practices to align with the language used around the science and engineering practices in the Next Generation Science Standards [87]. Figure 2.1 displays the taxonomy with the specific practices. The below sections describe each of the four practices.

Data Practices describe the different ways that students should be able to work with and understand data. Students must learn that raw data has to be sifted through and organized in order to find answers to their questions. These practices involve collecting, creating, manipulating, analyzing, and visualizing data. It also allows students to develop a deep understanding of how data can work for them to aid in their scientific investigations.

Modeling and Simulation Practices involve students creating models of phenomena. Students also explore the limitations of using their model to represent the phenomena under investigation (i.e., the simplification and assumptions necessary to build a model because it is not possible to model every single aspect of a system). Weintrop and colleagues [159] define *Computational models* as non-static representations of phenomena that can be simulated by a computer. Students use these computational models to define hypotheses and to see the phenomena represented in different ways. In addition, these practices ask students to design, construct, and assess computational models to build explanations for phenomena.

Computational Problem Solving Practices are the portion of the taxonomy most closely related to computer science. Computer science skills provide a framework to explore the sciences. These practices involve breaking down the problem into parts that can be investigated using computational tools and choosing the best computational tool based on the assessment of different approaches to solving the problem. These practices also involve the more traditional computer science principles of programming, modularity, abstraction, and debugging but applied to problems in mathematics and science.

The last category is *Systems Thinking Practices.* These involve defining the different systems under investigation and determining whether the system is appropriate for investigation. Students also think about the system as a whole, the different levels of the system, and relationships within the system. In addition, students learn to communicate information about the system to someone unfamiliar with it. It is essential that students not just divide the system into pieces but also examine how the entire system and its layers interact and relate.

Given that this framework is specifically designed to support the integration of computational thinking 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 computational thinking for the project.

2.1.2 Computational Thinking in Science

Science has become a field that is increasingly utilizing computational tools and design processes [44]. As the field increases in computational complexity, there has been a push to introduce computational tools and concepts into K-12 science classrooms. Introducing computational thinking in K-12 science classrooms prepares students for careers as scientists [5] and helps them see applications of computer science to other subject areas [94, 63].

Frequently, integrating computational thinking into science classes revolves around students building and using simulations of computational models about a topic they are currently learning about [138, 14, 159, 156]. Modeling provides an obvious entry point for computational thinking integration because it builds off the written models students already create. Computational models illustrate student models in action, and simulations allow students to observe processes that are either difficult to observe in a classroom setting or change slowly over time. Computational models and simulations are tools real scientists use to understand phenomena better.

Applications such as the Physics Education Technology (PhET) simulations[2] developed here, at the University of Colorado Boulder, allow students to view simulations of scientific phenomena such as static electricity on a balloon and run experiments through changing variables in the simulation and collecting data. The project began as a set of physics simulations [118], but has expanded to include ones in chemistry, biology, and earth science [162, 118, 103]. These simulations allow students to conduct experiments and observe phenomena in ways that would be impossible in the traditional classroom laboratory.

NetLogo[3] is an application that supports multi-agent, programmable computational models [156]. NetLogo allows students to interact with pre-created simulations similar to the PhET simulations. However, it also supports students and teachers creating computational models that

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[2] https://phet.colorado.edu/

[3] https://ccl.northwestern.edu/netlogo/

they can use to run simulations. It also supports numerous agents to model complex systems with many interacting pieces [163] instead of being limited to a small number of interacting components. A variety of science curricula [38, 88, 47] and academic research [19, 27], use NetLogo. It supports different depths of engagement with computational thinking based on how models are used or created.

While the computational models, such as those described above, do not readily accept input from real-world experiments, Blikstein [14] developed a bi-focal modeling framework where students 1) construct a computational model of the scientific phenomenon they are investigating, 2) set up an experiment to collect real-time data to validate their computational model, and finally 3) refine their computational model based on the experimental data collection. In testing the bi-focal modeling framework in high school science classes, Blikstein [14] found that if students did not create the computational model themselves, they attributed a mismatch between the model and experimental data to an error in the investigation rather than in the model. Without the technological empowerment that comes from building their own computational models, students are less likely to question the technology's correctness.

While computational modeling and simulations are popular means for integration, large data sets are becoming increasingly available online for anyone to use. Websites such as iSENSE[4] and CODAP[5] are specifically designed to cater to middle and high school teachers and students. Both tools enable the students to utilize real-world data sets to create and share analyses and visualizations [99, 41] with CODAP supporting students to generate data from simulations [41]. These applications allow students to see beyond the few sample points they can collect by hand and force them to think about issues associated with massive real-world data sets such as errors, outliers, and other issues related to the integrity of the data.

While computational modeling, simulations, and large scale data analysis provide many opportunities for integration, there are additional avenues of integration to explore. Programmable

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[4] http://isenseproject.org

[5] https://codap.concord.org/

sensor technologies are becoming increasingly accessible and affordable for K-12 classrooms [4] and provide students an opportunity to collect their own large data sets and automate experimental setups. These tools can allow for the expansion of the bi-focal modeling framework and other investigations that require collecting data to understand scientific processes.

2.2 Sensor Technologies

The increased availability of low-cost mobile sensors [4] is making it easier to measure and display information that was previously impossible for students to see. Microcontrollers such as the micro:bit[6] and LilyPad [21] support the ability for students to easily collect and respond to information from the environment through the incorporation of sensors such as temperature or light sensors. Even ubiquitous technologies such as Fitbits[7] and cell phones have internal sensors to measure things such as movement and heart rate. These sensor technologies provide new and innovative ways to understand and experience the world around us [66].

Sensor technology can help make the invisible visible. Norooz and colleagues [105] describe the creation of an e-textile t-shirt, 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 [105] by displaying heart rate, respiration, and digestion.

Sensor technology can also allow us to understand better how we interact with the world around us through movement. Lee and colleagues [93] had elementary school students wear fitbits to track their movement at recess. It was framed as a competition, and students examined their data each afternoon. This process helped them develop strategies for maximizing the number of steps they took and examined some common misconceptions such that specific steps would count more if they took more effort to complete, such as giving students piggyback rides. The data collected also fostered conversation around outliers (usually stationary periods) and why they occurred.

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[6] https://microbit.org/

[7] https://www.fitbit.com

Sensors allow for more than just passive data collection. InSPECT is a project from the Concord Consortium where students use sensors and actuators to create investigations and then use data flow software to run and control the experiments. Here students are not only collecting the data for their investigations; they are creating the data as well. The goal of this project is to turn students from mere data collectors into data producers [65].

Sensors that are deployable by the students allow for more personalized investigation and can provide different ways for students to connect to the physical world through movement [117, 93], investigations of phenomena that are otherwise difficult or impossible to observe [105], or come from abstract scientific theories [14].

The ability to easily collect large data sets can help offset a potential shortcoming with using data collected by other means. Utilizing prepopulated data collect streams allows students to interact with "big data" like scientists conducting their experiments.

However, since students do not collect the data themselves, they could overlook issues with the data more easily, similar to how students viewed the provided computational models as fact when they did not build the computational models in the bifocal modeling framework [14]. Students might see the data as fact and more easily dismiss data outliers and irregularities. However, preexisting data sets can serve as useful benchmarks and provide additional insight into the data collected using the sensors.

2.3 Science Education

Since the goal of this dissertation is to integrate computational thinking into mainstream middles school science classes, it is important to utilize the research on current best practices in science curriculum. Science education has been undergoing reforms throughout the last decade beginning with the development of *A Framework for K-12 Science Education: Practices, crosscutting concepts, and core ideas* [32], which introduces the three dimensions of science education: *disciplinary core ideas*, *science and engineering practices*, and *cross cutting concepts*. This framework provides the basis for the development of the Next Generation Science Standards [87]. One major goal of these recent reforms is making science class more like the real work of scientists [108] by combining the learning of content and practice [23].

2.3.1 Next Generation Science Standards

The Next Generation Science Standards(NGSS) [87] were developed by a collaboration of 26 states with both science education and industry leaders contributing. The goal was to develop a coherent sequence of standards for K-12 science education where knowledge built during the previous year provides the foundation for next year's learning through the interconnection of the three dimensions of science learning: disciplinary core ideas (DCIs), science and engineering practices (SEPs), and crosscutting concepts (CCCs), see Figure 2.2. The interconnectedness of these dimensions more closely resembles how scientist conduct their work [87, 23, 121].

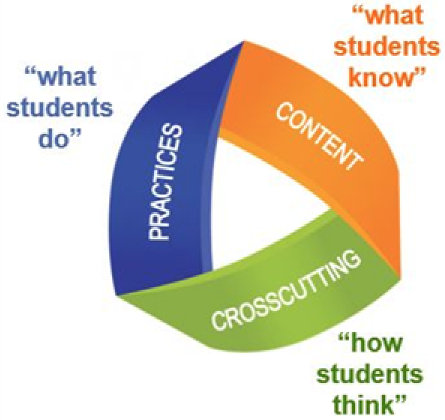

Figure 2.2: An overview of the three dimensions of learning science from the Next Generation Science Standards. Image from http://www.nextgenstorylines.org/

The DCIs represent the big science content ideas in the four core disciplines: Earth Science, Life Science, Physical Science, and Engineering. DCIs are broad scientific concepts that apply across disciplines, such as the ideas around ecosystems, including interactions within and among ecosystems, the dynamics between members of the ecosystem, and how energy flows within ecosystems (Life Science DCI). DCIs need to be broad enough to apply at all grade levels to support students understanding as they progress through school. As students advance in their understanding of DCIs, it does not mean that they simply learn more facts and details about the content but gain more in-depth knowledge into the *how* and *why* questions related to the DCI [39, 87].

SEPs represent how scientists engage in their everyday work. NGSS identified eight fundamental practices: 1) Asking Questions and Defining Problems, 2) Developing and Using Models, 3) Planning and Carrying Out Investigations, 4) Analyzing and Interpreting Data, 5) Using Mathematics and Computational Thinking, 6) Constructing Explanations and Designing Solutions, 7) Engaging in Argument from Evidence, 8) Obtaining, Evaluating, and Communicating Information. Students use the SEPs to help them build an understanding of the DCIs. They build a scientific community in their classrooms centered around using these practices to advance their knowledge [39, 147].

CCCs represent how students can think and reason about scientific phenomena. There are seven related concepts: 1) Patterns, 2) Cause and Effect, Scale, 3) Proportion and Quantity, 4) Systems and Systems Models, 5) Energy and Matter, 6) Structure and Function, 7) Stability, and Change. These concepts are represented across the DCIs and SEPs and 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. Looking at phenomena using different perspectives allows students to see new connections and understandings [39, 87].

Performance Expectations (PEs) include pieces of all the 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 [87]. The PEs are broken up by content area, with each of the four core subjects having their own PEs.

To design curriculum to implement the NGSS successfully aims for student-driven instruction that enables the students to “feel like scientists”, curriculum and teaching practices must be updated [33]. Penuel and Resier [111] outline seven principles for designing curriculum aligned to the NGSS and how these differ from instructional strategies used to implement previous science curriculum. They advocate for integrating the three dimensions throughout the curriculum instead of teaching content and practices separately. Phenomena anchor the curriculum in order to support incremental sense-making and knowledge building and avoid a disjointed sequence of lessons that teach content before practical applications. Lastly, 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 enable teacher learning. One instructional design technique that has proven successful in adhering to these principles is the creation of storylines [133, 122, 141] before the development of individual lessons.

2.3.2 Storylines

Storylines are created before individual lessons to serve as unit guides and ensure coherence and incremental knowledge building [133, 122, 141]. The first step is choosing the set of performance expectations (PEs) for the unit. Depending on the length of the unit, the number of PEs can vary from one to several. For example, a combination of the following PEs could serve as a bundle for exploring relationships in ecosystems: 1) Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem, 2) construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems, and 3) develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

After the determination of the PEs, the next step is to identify a phenomenon to anchor the unit. A scientific phenomenon is something that we can observe in real life, use our scientific knowledge to learn about, and explain our observations [3]. Some examples of phenomena include how the moon affects tides, what happens during a car crash, or how a maglev train works.

Storylines typically begin with an anchoring phenomenon routine (see Figure 2.3) that introduces students to the phenomenon that generates an overarching question for the unit, explore related phenomena, and their interactions and experiences with the phenomenon. These discussions culminate in the development of the driving questions board (DQB) [160], where the students document all the questions they have about the phenomenon and work with their teacher to develop categories of questions that will guide the remainder of the unit.

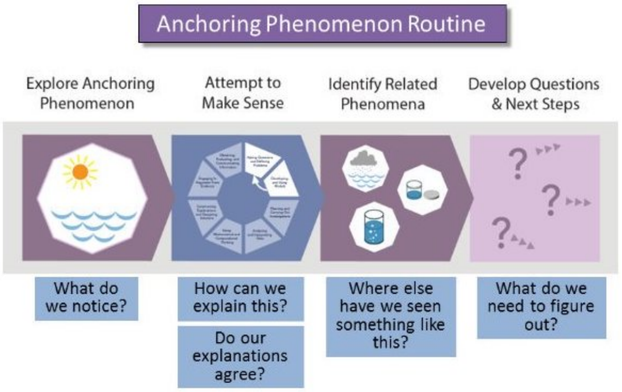

Figure 2.3: An overview of the anchoring phenomenon routine that begins by exploring the relevant phenomenon attempts to make sense of the phenomenon through explanation and model building brainstorms related phenomena that students might be more familiar with, and finally, creates a driving questions board to guide the remainder of the unit. Image from http://www.nextgenstorylines.org/

In addition to the anchoring phenomenon routine, four other routines support the creation and implementation of the storyline: the navigation routine, the investigation routine, the problematizing routine, and the putting pieces together routine [2]. The navigation routine promotes coherence across classes by always revisiting what students did yesterday at the beginning of class and planning for tomorrow at the end of class. The investigation routine is where students conduct investigations to help them figure out the answers to their questions utilizing the three dimensions of science learning. The problematizing routine pushes students to think deeper and revise their initial ideas around both their questions and the phenomenon itself. Finally, the putting pieces together routine is when students use the CCCs to put together the pieces of information they learned about the DCI to help them explain the phenomenon. Through answering the questions on the DQB, students develop an understanding of the phenomenon and overarching question that grounds the unit [134].

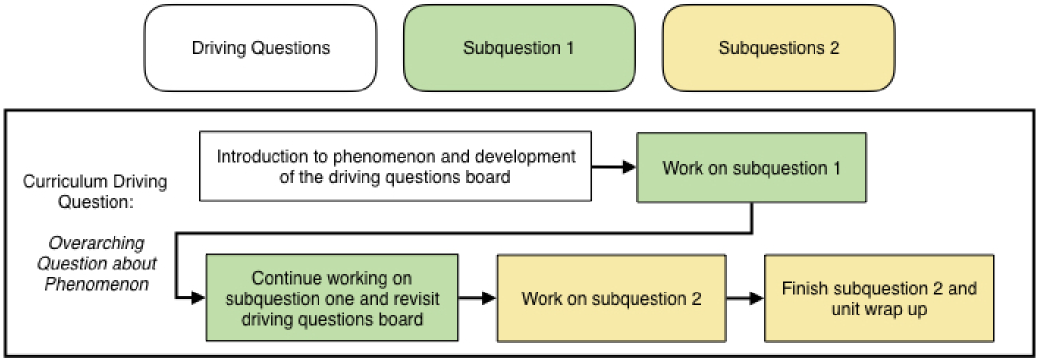

Figure 2.4: A storyline template that shows the flow of the set of lessons.

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 [123]. They enact the anchoring phenomenon routine themselves to understand the kinds of questions that students might generate and how students might categorize and prioritize them. From those questions, they build out "rows" in the storyline that correspond to the questions based on the prioritization process. Using the questions as the basis for each row aims to help students feel and act like scientists. They are drivers of the scientific inquiry process, rather than merely students who are learning about science [108]. Each row of the storyline describes what the students figure out concerning one of the questions they generated. The rows of the storyline provide a skeleton of a unit guide with each row roughly corresponding to a lesson (see Figure 2.4 for an example of the flow of a storyline in the classroom). The white box refers to the anchoring phenomenon routine, and the green and yellow boxes each correspond to a row in the storyline. After the creation of the storyline, the development of lessons corresponding to each row begins. The idea is first to develop out a high-level story, then go back to develop a sequence of lessons based on the storyline, thereby enabling a coherent lesson sequence. The coherent story helps the students make sense of the science they are learning [124, 134, 133].

One of the goals of NGSS is to promote equitable participation among students [32, 112]. When choosing phenomena to anchor the storylines, it is critical to tie the phenomenon to issues that are relevant and interesting for students to support motivation and promote more profound levels of thinking [16]. One strategy for choosing a phenomenon is to find ways to relate the phenomenon to students' schools, communities, or everyday lives.

2.4 Place-Based Education

There is much discussion in STEM education about equity [157]. Chapter 1 addressed one issue of equity: access to STEM education. However, equity goes much beyond equal access; it also must entice students from underrepresented groups to take advantage of this access [157]. Frequently STEM learning is thought of as acultural. What is cultural about chemistry, mathematics, or engineering? Focusing on STEM as acultural can lead to conclusions that low income, minority students are at a deficit when it comes to their peers whose culture more traditionally aligns with STEM curriculum. The curriculum can have unintended consequences of forcing these students into viewpoints that run counter to their culture. This disconnect can lead to students becoming unengaged with school and seeing learning as a separate process from community participation [7].

A critical pedagogy of place as defined by Gruenewald [58] emphasizes a curriculum grounded in the community and ecological environment with a focus on cultural politics and how they affect both the community and the rest of the world. He describes this as a twofold process:

- *Decolonization*: breaking down the dominant and oppressive cultures; and,
- *Reinhabitation*: teaching us how to live well in the total environment.

The curriculum focuses on helping the students develop the skills necessary to be contributing members of the community by grounding their education in local issues and places, but not without the thought of where they fit in a larger society.

The critical pedagogy of place "encourages young people to connect local issues to global environmental, financial, and social concerns such as climate change, water scarcity, poverty, and trade" [100]. It focuses on empowering students to see what is possible and how they can personally affect the future. The critical pedagogy of place focuses on transformative education where the teacher's role transforms into that of a mentor and critical friend who investigates alongside the students instead of directing them or letting them explore unaided [22].

Social problem solving through science [22] emphasizes the *why here?* and *so what?* questions that are essential for providing context to scientific investigations as well as to implementing a critical pedagogy of place. A summer program where students explored water quality and weather from local and global perspectives tested the curriculum [22]. The curriculum grounded the student investigation in a nature study of a local lake using a variety of tools and sensors to test different aspects of water quality and examine the local weather patterns. Students discussed global issues such as the availability of clean drinking water. They created a public service announcement based on an environmental issue related to water quality or weather connecting local investigations to global community issues. In the end, the students did not increase their science knowledge. However, they had more detailed explanations of specific environmental issues and some of the social consequences, which is a step toward becoming engaged members of the community. While the study showed limited results, it did provide an example of how to deconstruct science learning into both local investigations and a critical examination of those issues.

Bang and Marin [7] examine nature-culture constructs in science education to create a more equitable, engaging curriculum. They studied conversations in a middle school environmental science education program for Indigenous students and the conversations of Indigenous children and parents on walks in the forest. The goal of the conversations is to redefine space-time relationships with nature and culture using decolonization methodologies to illustrate the value of indigenous peoples' ways of knowing how humans are connected to the plants, animals, and landscape of the natural world instead of outside it. In the first case, the teacher illustrates this by grounding the curriculum in the Miami language bringing the Miami ways of knowing into the present and representing them as part of the curriculum. In the second case, the mother speaks in the present tense when discussing the potential agency of a tree that her son says is watching him. The authors argue that expanding the science learning environments to include and value indigenous knowledge is vital to prevent dichotomy between school and home. Utilizing interrelations between nature and culture provides students an opportunity to better understand how science is relevant to them and not separate from the community.

These examples illustrate potential applications of the critical pedagogy of place to science instruction in order for students to develop new understandings and connections between themselves, their communities, and the world around them. Building off of these ideas, this dissertation examines how the critical pedagogy of place can apply computing as a medium for expression and learning to increase the personal relevance of computational thinking and inspire the next generation of computational participators [75].

Chapter 3

Research Context

This dissertation involves work undertaken as part of the larger SchoolWide Labs project that aims to broaden participation in computational thinking activities through place-based, sensor-driven investigations in required middle school science classes. Middle school students are the targeted demographics because middle school is a time when students begin to form identities around their interest and ability in STEM fields that will influence which courses they pursue in high school [40, 151, 142]. This is especially true of women who are traditionally underrepresented in STEM majors and careers [104, 15]. This chapter describes the SchoolWide Labs project as a whole and puts the focus of this dissertation into context.

SchoolWide Labs builds on a long-standing Research-Practice Partnership (RPP) [29, 28, 109] between University of Colorado Boulder and Denver Public Schools. Research-Practice Partnerships work towards using research to improve educational practice through building long term collaboration between researchers and practitioners who work together to solve common problems of practice [29]. The existing RPP worked with District Science and STEM administrators and high school teachers to design a year-long biology curriculum aligned to the Next Generation Science Standards [140, 89, 46]. SchoolWide Labs expands this RPP to work with middle school science and Integrated STEM[1] teachers to bring computational thinking into their classrooms through the use of programmable sensor technologies. In addition, SparkFun Electronics, a small electronics company located in Colorado, joins the partnership as the primary developer and provider of the

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[1] This is a required middle school class covering topics such as civil engineering, robotics, and computer science most often through problem-based learning.

programmable sensor technologies. SparkFun joined the RPP intending to expand its understanding of how to integrate technology into science classrooms.

3.0.1 Design Approach

The research team utilizes a design-based implementation research (DBIR) approach developed by Fishman and colleagues [42] to develop the SchoolWide Labs project in the context of the RPP described above. DBIR is an approach to research that is particularly well-suited to conducting research in the context of an RPP [42] because its goal is for teams of researchers and practitioners to collaboratively solve problems of practice in education to produce sustainable change. DBIR has four key components: *(1)* The problems are explored from the perspective of multiple stakeholders. *(2)* The design process is both collaborative and iterative. *(3)* The entire team has the goal of developing knowledge around learning and implementation. *(4)* The main goal of the design work is to produce sustainable change.

The first step in a DBIR project is to choose a problem of practice relevant to all stakeholders [42]. This is not a one-sided relationship in which researchers come into a school to tell practitioners what problems they will solve, but rather a two-way discussion of the problems practitioners have and a joint collaboration towards solving the problem. In this work, Denver Public Schools highlighted their need to integrate computational thinking experiences into their classrooms in equity-driven ways.

After choosing a problem of practice, new educational interventions to address the problem are developed and refined through iterative design cycles involving field deployment and data collection [42]. DBIR emphasizes the cyclic nature of the design work, where reflections from previous implementations influence the next development session. A core part of these iterative design cycles is collaborative design (co-design) between researchers and practitioners, including the teachers who implement the lessons. Taking an active role in the generation of their curriculum and accompanying lesson materials ensures that teachers have an influential voice and sense of agency in the initiatives that affect their daily practice [78, 140]. In this work, middle school teachers and administrators served as our co-design partners with the teachers implementing the lessons in their classrooms.

3.0.2 SchoolWide Labs

Through conversations with Denver Public Schools that highlighted the need to integrate computational thinking in equity-driven ways that guaranteed exposure for all students, researchers and practitioners came together to create SchoolWide Labs. SchoolWide Labs consists of a three-pronged system outlined in Figure 3.1. The School Sensing Platform is a set of programmable sensor technologies that students can use to collect real data about the different scientific investigations they undertake. The productive integration tools consist of supports such as model curricula and activities to be used by both teachers and students to demonstrate the integration of computational thinking into science instruction. The CT-Integration Cycle is a professional development model to support teachers in implementing CT-integrated science lessons. SchoolWide Labs explores the kinds of supports that teachers need to implement lessons that include computational thinking and the use of programmable sensor technologies. The project also investigates how students perceive the units and what knowledge they build around both computational thinking and science. One goal of the project is to produce both classroom and professional development toolkits that can support teachers (outside of the research participants) to engage with the developed materials.

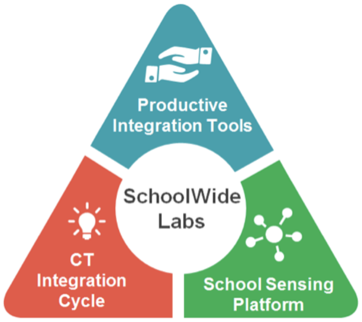

Figure 3.1: SchoolWide Labs framework for CT-integration.

Three design cycles have been completed for SchoolWide Labs with each design cycle corresponding to one calendar school year beginning in the Fall of 2017. Each design cycle investigates all three components of SchoolWide Labs: the use of a school-based sensing platform, the development of productive integration tools, and one iteration of the CT-Integration. The next three sections in this chapter provide details on the three components of SchoolWide Labs. Section 3.4 provides a summary of each design cycle.

3.1 School Based Sensing Platform

Science is becoming a discipline that relies more and more on the use of technology [44, 5]. One goal of the next generation science standards is to provide students more authentic learning experiences that mimic the work of scientists [87, 122, 108]. One way to support this process is to use computational models and simulations [118, 159, 56] or to use large data sets that are increasingly available online [99, 41]. Section 2.1.2 discussed some of the drawbacks of these. However, new sensor technology that allows students to collect, analyze, and display data is becoming increasingly accessible to the general public through decreased cost and improved robustness [59].

The school-based sensing platform is a set of programmable sensor technologies that supports both the integration of computational thinking and the relevance that place-based investigations can offer students. The platform 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. During each design cycle, the sensor technology is updated and refined in collaboration with SparkFun based on initial findings. The specifics around the sensor technology used in each design cycle is described in detail in Section 3.4.

While sensor technologies provide students authentic experiences in using the tools of scientists, they also provide a medium with which to ground the integration of computational thinking – the original goal of the project. Note that the mere act of using tools in science classes is not enough to claim that the students are engaging in computational thinking while using the tools. The activities need to promote the thought processes associated with computational thinking while engaging with sensor technologies.

To understand how the utilization of the sensor technologies can promote computational thinking, the research team draws on the Computational Thinking in STEM Taxonomy developed by Weintrop and colleagues [159]. The Computational Thinking in STEM Taxonomy focuses on integrating computational thinking into science and aligns its language with the Next Generation Science Standards (NGSS) Science and Engineering Practices (SEPs) [87] that are familiar to teachers. It defines four categories of practices: Data Practices, Modeling and Simulation Practices, Computational Problem Solving Practices, and Systems Thinking Practices. Section 2.1.1 discussed the details of the Computational Thinking in STEM Taxonomy. For the remainder of this dissertation, the phrase CT Practices refers to the Computational Thinking in STEM Taxonomy. The terms Data Practices and Computational Problem Solving Practices refer to the specific groups of practices outlined in the Computational Thinking in STEM Taxonomy. SchoolWide Labs focused first on these two sets of practices.

Data Practices represent a familiar entry point for teachers, since many are already doing certain kinds of data analysis in their classrooms. Also, a central purpose of sensors is to support the collection of large amounts of data. Sensors provide the capability of students to both collect and create data [159, 65]. To wrangle with large amounts of data, students must go beyond traditional tasks that ask them to examine a few data points collected by hand. It provides opportunities for productive discussion around how to make sense of large data sets and how to process them to understand the questions the students are trying to figure out. Lastly, the sensor technology supports new ways of visualizing and communicating about the data collected through infographics and physical data displays.

The Computational Problem Solving Practices are critical for students to utilize the programmable aspects of the sensor technologies. Programming the sensor technologies to collect, analyze, and visualize information provides students the opportunity to engage in computational problem solving practices. Students utilize *abstraction* through the recognition of common data collection and analysis strategies. The development of common routines across experiments, such as a function that collects data from any sensor, is an example of how students can use *modularity*.

Students *debug* their programs to ensure accurate data collection. While the use of programmable sensor technologies is relevant to some of the students' investigations, other inquiries would not benefit based on the kinds of data needed and the questions the students want to answer. Since sensor technologies are not always relevant, this presents a learning opportunity for students to have to justify the use of the tools.

The close relationship between the programmable sensor technologies, data practices, and computational problem solving practices provides an innovative way to cultivate students' interests by connecting to their personal experiences through investigations grounded in their school and community. Prior research discussed in Section 2.4 suggests that *place* can offer a powerful tool for engaging learners from underrepresented groups in STEM, through investigations focused on personally or locally relevant scientific phenomena [120, 4, 77, 154]. In place-based investigations, questions such as *why here?* and *so what?* surface prominently and provide a context for the phenomenon students are learning about [22]. In particular, large data streams used with data practices can support students in engaging in critical data storytelling about places that matter to them [77]. Throughout the experience of creating these stories, students can develop their computational thinking perspectives [18] by asking questions, sharing their results, and connecting their data to others.

3.2 Productive Integration Tools

When integrating new ideas into science classes, it is important to utilize research at the forefront of science education. The Next Generation Science Standards (NGSS) [87] are the state of the art set of standards that aim to make science classes more faithfully recreate the experience of daily life as a scientist. The goal is to integrate science content with "doing science", referred to as science practices, thus making instruction more student-driven in classes where students can "feel like scientists". The thought processes shared across science content, such as recognizing patterns, are referred to as the crosscutting concepts. Together these ideas are referred to as the three dimensions of science learning.

The goal of the project is to integrate computational thinking into middle school science classes using programmable sensor technologies. To this end, the development of tools supports the process. The research team investigates how these support tools help both teachers and students engage in productive integration of computational thinking. This section describes the support tools under development, namely, supports for teachers to create and modify units that integrate computational thinking using programmable sensor technologies. These units also must support current best practices in science instruction—thus showing that the addition of these new pieces enhances (or at least does not detract from) three dimensional science learning [164, 9].

One strategy that has proven successful for designing curricula aligned to the NGSS is the creation of storylines [133, 122, 141] centered around a scientific phenomenon that serves to anchor the unit. The creation of storylines is an instructional design technique where predicted student questions about a scientific phenomenon are used to outline a coherent sequence of lessons that support incremental knowledge building around the three dimensions of science learning tied to that phenomenon [133, 122, 141]. These storylines are created before the specific lessons for the unit to serve as a unit guide. Members of the research team have significant expertise in designing storylines for high school science [89, 88, 46]. Over the three years of the project, the research team, in collaboration with teacher partners, has designed three storylines and corresponding lesson sets that integrate computational thinking and programmable sensor technologies. These storylines and corresponding units serve as exemplars in understanding how to use the storylining technique to bring new computational tools into the classroom in authentic, student-driven ways. For more details on storylines, see Section 2.3.2.

Anchoring phenomena are the centerpiece of a good storyline providing an opportunity for deep engagement with the three dimensions of science learning. Of critical importance for the research team is finding an anchoring phenomenon that 1) allows for the sensor technologies to be meaningfully integrated throughout the unit, 2) aligns with the middle school science standards, and 3) is locally relevant and compelling for students. The goal of fitting these constraints is to support motivation and promote deeper levels of thinking [16] in the students. Finding such phenomena is challenging and requires thinking outside the box about how to utilize the programmable sensor technologies best.

While several units integrating the programmable sensor technologies into science are in circulation, an additional goal is to support all teachers, including those not involved in the project, to adapt their existing curricular materials to be driven more by students' questions and to integrate the sensor technologies where appropriate. After the three design cycles, the research team will examine strategies for supporting teachers in this endeavor. A natural starting point is to begin with teachers who have been participating in the project. These teachers become leaders of professional development workshops where they support new teachers in implementing existing units created during the project and the adaptation of new units from their curriculum. This strategy is one way to build sustainable change from the results of the project.

3.3 CT-Integration Cycle

In order for science and Integrated STEM teachers who have little to no prior experience using programmable sensor technologies to integrate computational thinking in their lessons deeply, teachers need enriching professional development experiences. The CT-Integration Cycle is a professional development approach to help build teacher capacity to implement CT-Integrated instructional activities. The CT-Integration Cycle combines elements of two successful professional development models: collaborative design (co-design) for the development of science curriculum [127, 115, 89, 107, 114] and the problem solving cycle (PSC) originally developed to support math teachers [73, 17, 72]. The SchoolWide Labs research team are deeply experienced with both these models from prior and other ongoing projects [115, 89, 107, 114, 73, 72].

Co-design involves researchers and practitioners working closely together to develop novel educational innovations. It is a productive curriculum building experience [42, 140], especially for science curriculum [114], providing a way to increase teachers' engagement with and investment in the curriculum and bolster their feelings of agency around the curriculum [140]. The co-design process integrally involves the teachers' expertise when developing the curriculum and lessons. It helps ensure that the resulting units are both feasible and appropriate for their local school context. Since co-design often involves working with classroom teachers, the design cycle usually takes place over one school year, beginning with a multi-day design workshop during the summer and regular meetings throughout the school year [115].

The PSC is a successful mathematics professional development model designed to help teachers improve their instruction through closely examining mathematics problems, student thinking, and pedagogical practices through video analysis of actual classroom implementation [17]. The workshop series focuses on the classroom implementation of one math problem centered around a topic known to be challenging to students such as ratio and proportion. These workshops aim to help teachers learn how to elicit and build on student thinking and explore instructional strategies for teaching. These videos allow teachers to learn about their practice and explore how other teachers implement the same lesson. One cycle consists of three to four workshops with the beginning workshops focused on *planning* for the implementation and the later workshops on video-guided *reflection* of that implementation.

The CT-Integration Cycle combines these two models into one, as illustrated in Figure 3.2. The co-design model supports the design of new CT-integrated curricula and activities, highlighted in green. The PSC provides a lens to examine the classroom implementation of key features of the co-designed curriculum, highlighted in yellow. Each cycle consists of a three to five-day summer design workshop and four full-day workshops throughout the school year. The sections below describe each workshop in detail.

3.3.1 Summer Design Workshops

The summer design workshops offer teachers time to dive deeply into co-designing a new unit and explore how computational thinking and sensors factor in. These summer workshops establish a co-design culture to support teacher agency through the workshop series during the following school year [140].

This process begins by unpacking the science content defined by the performance expectations

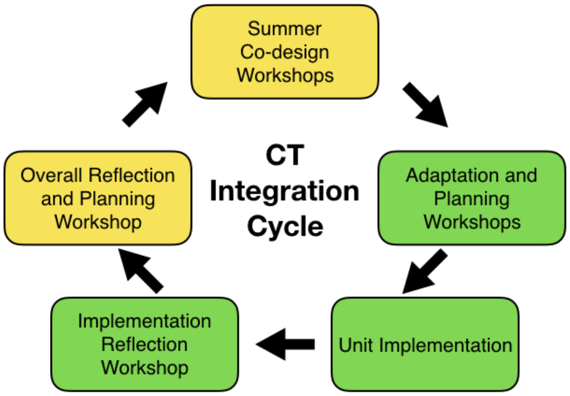

Figure 3.2: The CT-Integration Cycle. The yellow boxes represent workshops that rely heavily on the co-design model and the green boxes represent workshops that rely heavily on the PSC model.

(PEs) in the Next Generation Science Standards. Unpacking means deconstructing the language of the PEs into more detailed descriptions of what the PE means and how it looks in the classroom [83]. After this process, teachers brainstorm phenomena based on a set of PEs they want to investigate with their students, the different capabilities of the sensor system, and the connections between the phenomena and students' school and community. This process concludes with identifying a phenomenon (or phenomena) as candidates to anchor the new storyline.

If multiple phenomena are selected, teachers and researchers form mixed groups to explore a phenomenon in more depth by 1) hypothesizing potential student questions, 2) exploring the applicability of the programmable sensor technologies, and 3) developing student artifacts that illustrate how students are engaging with the performance expectations. The process of involving teachers in the choice of the phenomenon is another example of how the research team seeks to provide agency to the teachers [140]. Each group then presents their work, and the teachers vote on which phenomenon to pursue further.

After a phenomenon is selected, the research team collaborates with the teachers to collaboratively develop the new storyline using Google Docs, a process similar to the one used to develop high school biology storylines [113]. The use of Google Docs allows all workshop participants to work simultaneously and easily allows the research team to track changes across the document. This storyline document evolves across not only the summer workshops but throughout the school year. The first step in creating the storyline is through acting out the anchoring phenomenon routine to develop the set of questions that become the basis for the rows in the storyline.

Each row in the storyline corresponds to a lesson or set of lessons for the unit. After the establishment of the rows, teachers and researchers form groups to work on specific rows highlighting what students are doing during each of the lessons (written in student language) and the potential artifacts they create. Each group dives deep into the phenomena, explores how students will collect and display data, and develops a final exemplary student model. In addition to the description of what students do, specific notes highlight the integration of computational thinking, sensors, and the idea of place.

While the design work is the main focus of the summer workshop, a necessary component is to provide a time for teachers to engage in computational thinking activities and learn more about the programmable sensor technologies. Teachers spend time exploring the sensor technologies through the creation and design of simple data collection programs and data displays. This process builds their capacity to integrate the sensors and computational thinking into the storyline.

3.3.2 Adaptation and Planning Workshops

The first two workshops focus on adapting and planning the unit's implementation based on the storyline developed during the summer workshop. Between the summer workshop and school year workshops, the research team works to write lessons and assemble materials necessary for implementation. The workshops provide time for teacher feedback on these materials and time to practice certain parts of the lessons to prepare for implementation. The "student hat"/"teacher hat" paradigm [80, 36, 24], where either a researcher or a teacher volunteer to lead a lesson as written and the rest of researchers and teachers participate as students, helps elicit feedback on the materials. A deconstruction of their experiences follows the lesson from a teacher's point of view (i.e., wearing their "teacher hat"). The "student hat"/"teacher hat" process allows teachers to see how such an implementation might play out in their classrooms and to address any three dimensional content issues such as investigations that only support superficial engagement with the DCI or problems with coherence. Teachers then provide feedback through a verbal discussion and insert comments and suggestions directly into the storyline and lesson documents. These revisions ensure that the teachers feel well prepared to implement the unit during the school year. Depending on the storyline's length, all lessons may be visited, or a subset of lessons that the researchers feel would most benefit with additional input from the teachers.

In addition to providing feedback on the development of the lessons, the teachers engage in collaborative planning for the unit's implementation. This draws directly on the PSC, where teachers collaboratively plan for the implementation of one specific math problem [73, 17]. Whereas the PSC model focuses on the implementation of one math problem, the CT-Integration Cycle workshops focus on an entire unit but highlight specific portions for collaborative adaptation and planning. Thus far, the focus has been on the anchoring phenomenon routine and lessons that focus heavily on computational thinking and sensor usage. These two areas are the initial targets because executing a good anchoring phenomenon routine is a prerequisite for promoting students driving instruction through the unit, and the integration with computational thinking through the use of programmable sensor technologies represents a central point of investigation for the research team.

3.3.3 Unit Implementation

All teachers implement the co-designed unit based on the storyline between the Adaptation and Planning Workshops and the Implementation Reflection Workshop. During implementation, researchers are present to videotape key lessons focusing on the anchoring phenomenon routine and the usage of the programmable sensor technologies. These are the lessons emphasized during the Adaptation and Planning Workshops. The videos are utilized in a similar manner to the problem-solving cycle [17] to provide a basis for discussion during the Implementation Reflection Workshops. As implementation is ongoing, researchers meet in a small group to discuss each teacher's progress and share key pieces of video such as a particularly successful creation of a driving questions board or a unique way a teacher introduces the sensor system to their students.

In addition to video from the implementation, the research team also collects student artifacts and conducts post-implementation interviews with the teachers to provide additional context to their classroom video. To understand how students experienced the unit, the research team collects surveys related to coherence, relevance, and perceived contribution throughout the implementation. These surveys are based on similar surveys using in the high school biology curriculum [116].

When all teachers have finished implementing the unit, the research team gathers to discuss themes seen across the classrooms and to plan for the implementation reflection workshop.

3.3.4 Implementation Reflection Workshop

The third workshop offers time for reflection on the implementation using classroom video, student artifacts, and student survey results. Since teachers implement the unit anytime after the Adaptation and Planning Workshops and before the Implementation Reflection Workshop, the day begins with written reflections to prompt them to think back upon their specific implementation. The remainder of the workshop revolves around discussion focused on the different aspects of the implementation, based on classroom video and student outcomes, through examining both student artifacts and student survey results.

The viewing of the classroom video follows the strategy for leading discussions based on classroom video from the problem solving cycle [17]. The discussion begins with teachers viewing the video and reviewing how they enacted that portion of the storyline. If the video represents an implementation feature unique to that teacher, the discussion begins with the teacher in the video describing the rationale behind their actions. The goal is to have discussions about the instructional strategies the teacher used during the video, how those instructional strategies worked in the context of the interaction, and how to develop further or improve them. Examining student artifacts follows a similar structure, with the majority of the artifacts discussed coming from an adaptation or addition that the teacher made to the unit. These artifacts often represent ways in which students delved deeper into three dimensional science learning, computational thinking, sensor usage, or the relevance of place.

Student surveys are presented to the teachers in aggregate for all teachers with the option to have individual results communicated privately. The surveys fuel discussion around whether teachers' perceived experience matches the students' actual experience. The surveys are given several times throughout the unit, so low scores or differences across lessons can give a baseline target for revisions.

3.3.5 Overall Reflection and Summer Planning Workshop

The fourth workshop is a time for the teachers and researchers to reflect on the previous year of the CT-Integration Cycle and plan for the upcoming summer design workshops. The reflection portion consists of teachers responding to questions about the processes they engaged in throughout the year and discusses ideas for revision for the upcoming year, including aspects of the design process, unit produced, and the programmable sensor technologies. Teachers reflect on how their views of computational thinking have evolved over the course of the year and how the sensors have influenced their science instruction. This process aims to make sure that teachers' and researchers' experiences and goals for the upcoming year are in alignment.

Part of the fourth workshop is devoted to the exploration of new aspects of the programmable sensor technologies. Teachers spend time working with the new programmable sensor technologies through the creation of new programs and data visualizations. After investigating the capabilities of the updated technology, they brainstorm new ways to integrate it into their classrooms and support students as they undertake their scientific investigations.

The end of the workshop consists of choosing a set of Performance Expectations and brainstorming new phenomena that support the Performance Expectations and have the potential for deep integration of sensor technologies throughout the unit. The summer workshops replicate this process in more detail. This workshop provides the research team with information to design the summer workshops with input from the teachers.

3.3.6 Computational Thinking and Sensor Usage

Throughout all of the workshops, a running theme is computational thinking supported through the use of sensor technologies. These are topics that most science teachers are not familiar with, and struggle with defining and identifying whether their students are actually engaging in computational thinking.

Many teachers lack confidence in using new technology with their students in the classroom.

Thus each workshop includes time devoted to the exploration of computational thinking and sensor technologies. Activities included with the process are an unpacking [83] of the Computational Thinking in Science and Math Taxonomy [159] with focus on the data practices and computational problem solving practices. These activities help teachers see how the CT data practices differ from the kinds of experiences their students are currently having involving data and help introduce them to the less familiar computational problem solving practices.

Teachers experience potential lessons and activities as students and then dissect them as teachers for connections to the practices and modifications necessary for implementation in middle school classrooms. For a detailed discussion about how computational thinking and the use of sensor technologies played out during the first two iterations of the CT-Integration Cycle, see Chapter 4.

3.4 Design Cycles

This section outlines the three design cycles including information about the participants, sensor technologies, and storylines. Table 3.1 summarizes all design cycles.

Table 3.1: Overview of the three design cycles. One science teacher who had a different role during the 2018-2019 school year is returning for the third cycle.

	Cycle 1: 2017/2018	**Cycle 2**: 2018/2019	**Cycle 3**: 2019/2020
Phenomena	Mold Growth: Students learn about what mold needs to grow and investigate their school for the conditions that support mold growth.	Maglev Train: Students learn about how maglev trains work through experiments around magnets and electromagnets. They also explore what might happen if a maglev train was built in their neighborhood.	Teachers have a choice over modifying and implementing an existing unit or implementing a compost unit that explores how composting works and its purpose in an urban environment. Also, they will implement a sensor immersion experience at the beginning of the school year.
Sensor System	Custom Sensor System built by SparkFun. It uses a ESP-32 Board equipped with an environmental combo sensor that measures temperature, humidity, pressure, altitude, carbon dioxide, and total volatile organic compounds and an SD that records the measurement from the sensor every second.	Micro:bit programmed by the students using MakeCode. The micro:bit has four onboard sensors: temperature, light, accelerometer, and magnetometer. A custom-built Chrome Application supports data collection.	Gator:bit that exposes additional pins on the micro:bit and additional sensors including the environmental combo sensor from Cycle 1, sound, more accurate temperature, and light sensors, particle sensor, soil moisture sensor, and UV sensor. Students can add a real-time clock and data logger that stores data on an SD card.
Length of Implementation	One Week	Three Weeks	One Week Sensor Immersion, One to Three Weeks depending on what unit the teacher implements.
Teachers	4: 3 Science, 1 STEM	5: 3 Science (1 returning) and 2 STEM (1 returning)	10: 7 Science (4 returning), 3 STEM (0 returning).
Students	363	488	971

3.4.1 Participants

The research team worked with administrative partners at DPS to select the teacher participants for the project. The goal was to select both science and Integrated STEM[2] teachers since those are the two required subjects targeted for integration. The administrators at DPS vetted teachers interested in participating to confirm that they understand what the project entailed (i.e., that they will participate in multiple workshops throughout the year to co-design with researchers and implement curriculum integrating computational thinking and programmable sensor technologies). The teachers ranged in experience and grade level taught. Table 3.2 outlines all participating teachers for the three cycles along with demographic information about their school and demographic information (if available) about their specific students. Demographic information about the students is collected using a student survey administered during the unit implementation.

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[2] Integrated STEM is a required class in Denver Public Schools that covers a variety of science and engineering topics ranging from civil engineering to computer science.

Table 3.2: Table outlining the participants for the three design cycles. FRL means free and reduced lunch. All names are pseudonyms. For Cycle one, Jacob did not administer the survey for demographic information. For cycle three James, Teresa, and Adriana did not administer the survey for demographic information.

	Teacher	Subject Taught (years experience)	Grade	School FRL	Students (survey answers)	Gender	Ethnicity
Cycle One	Carolyn	STEM (4)	5	7% FRL	90 (52)	50% Female	11% nonwhite
	Jacob	Science (20+)	6	94% FRL	100 (0)	Not Available	Not Available
	Trent	Science (2)	7	94% FRL	148 (111)	55% Female	94% nonwhite
	Andrew	Science (9)	8	64% FRL	63 (50)	43% Female	70% nonwhite
Cycle Two	Carolyn	STEM (5)	5	6% FRL	89 (30)	53% Female	20% nonwhite
	Tracy	Science (4)	6	95% FRL	103 (35)	50% Female	94% nonwhite
	Trent	Science (3)	8	94% FRL	135 (109)	47% Female	96% nonwhite
	Matthew	STEM (3)	7	74% FRL	147 (18)	47% Female	90% nonwhite
	James	Science (3)	7	80% FRL	149 (100)	40% Female	93%nonwhite
Cycle Three	Tracy	Science (5)	6	95% FRL	71(21)	39% Female	100% nonwhite
	Trent	Science (4)	8	95% FRL	134(89)	46% Female	97% nonwhite
	James	Science (4)	7	83% FRL	148(0)	Not Available	Not Available
	Andrew	Science (10)	7	91% FRL	70(52)	42% Female	100% nonwhite
	Teresa	STEM (-)	8	64% FRL	70(0)	Not Available	Not Available
	Mark	Science (2)	7	95% FRL	145(86)	44% Female	97% nonwhite
	Zane	Science (2)	8	91% FRL	76(67)	34% Female	97% nonwhite
	Adriana	STEM (11)	7/8	95% FRL	56(0)	Not Available	Not Available
	Ethan	STEM (8)	6/7	95% FRL	53(34)	37% Female	91% nonwhite
	Victoria	Science (2)	6	91% FRL	115(45)	52% Female	93% nonwhite

3.4.2 Design Cycle One

The first iteration of the project began in September 2017. DPS administrators selected a four-person teacher advisory board as co-design partners for the 2017/2018 school year. Part of their participation included implementing activities using the sensor system during the spring. The first year was an exploratory process that allowed the research team to pilot the custom sensor system that SparkFun was building and develop activities and tools to support the teachers in implementing computational thinking activities.

For the first year of the project, the team worked with the same four middle school teachers from Denver Public Schools, see Table 3.2, three science and one Integrated STEM. The STEM teacher implemented the program with her fifth-grade class, and the three science teachers represented sixth, seventh, and eighth grade. For the first year, the teachers implemented a unit focusing on mold growth in schools with a total of 363 students.

Since the project began in the Fall, there was no time to run a summer workshop for teachers. Thus, the research team had to take on a more significant role in the creation of the initial storyline, which involved investigating the school for the conditions for mold growth (see Figure 3.3). Students figure out what mold needs to grow and use the sensor technology to explore their school environment for the conditions for mold growth. The unit concludes with students determining the places in their school most likely to support mold growth and what might happen in a location that would cause mold to grow.

Four reasons were supporting the anchoring phenomenon of mold shutting down a school. 1) The first version of the sensor technology included the environmental combo sensor, which can measure temperature, humidity, pressure, altitude, carbon dioxide, and total volatile organic compounds. The environmental sensor supported students collecting information to identify temperature and humidity conditions that corresponded to hospitable environments for mold growth, see Figure 3.4 for a depiction of the first version of the sensor technology. 2) The investigation of mold growth in their schools allowed students to get outside of the traditional lab environment and explore their entire school, providing a locally relevant context tied to the students' place [120, 22]. 3) The concept of how mold growth supports the middle school life science performance expectation, MS-LS2-1: *analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.* Lastly, 4) in conjunction with the performance expectation, the unit supports several computational thinking data practices: the collection of data using the sensor technology and the analysis and visualization of that data using Google Sheets. It did not readily support additional computational thinking practices because it was pre-programmed for the students by SparkFun engineers to collect all sensor readings once every second.

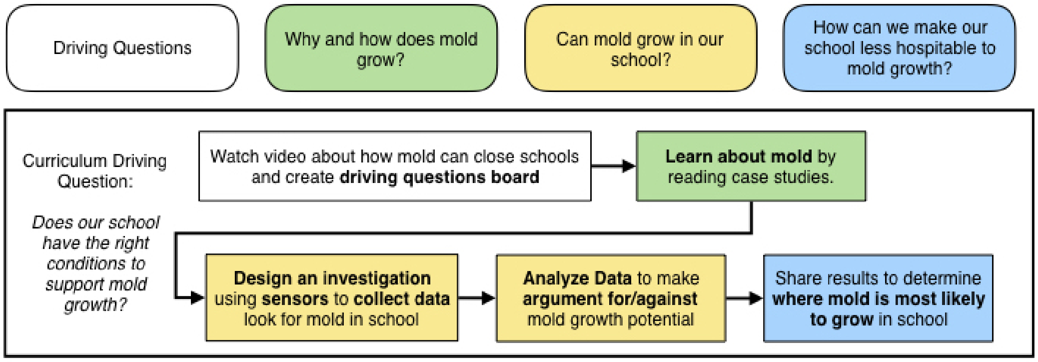


Figure 3.3: Storyline of the mold unit that addresses the question: Does our school have the right conditions to support mold growth? The bold text in the graphic refers to the science content and science and CT Practices.

Figure 3.4: The sensor technology from cycle one including a front and side view. The red square is the environmental combo sensor. The LED labeled STAT turns green every time the readings from the sensor systems are written to the SD Card.

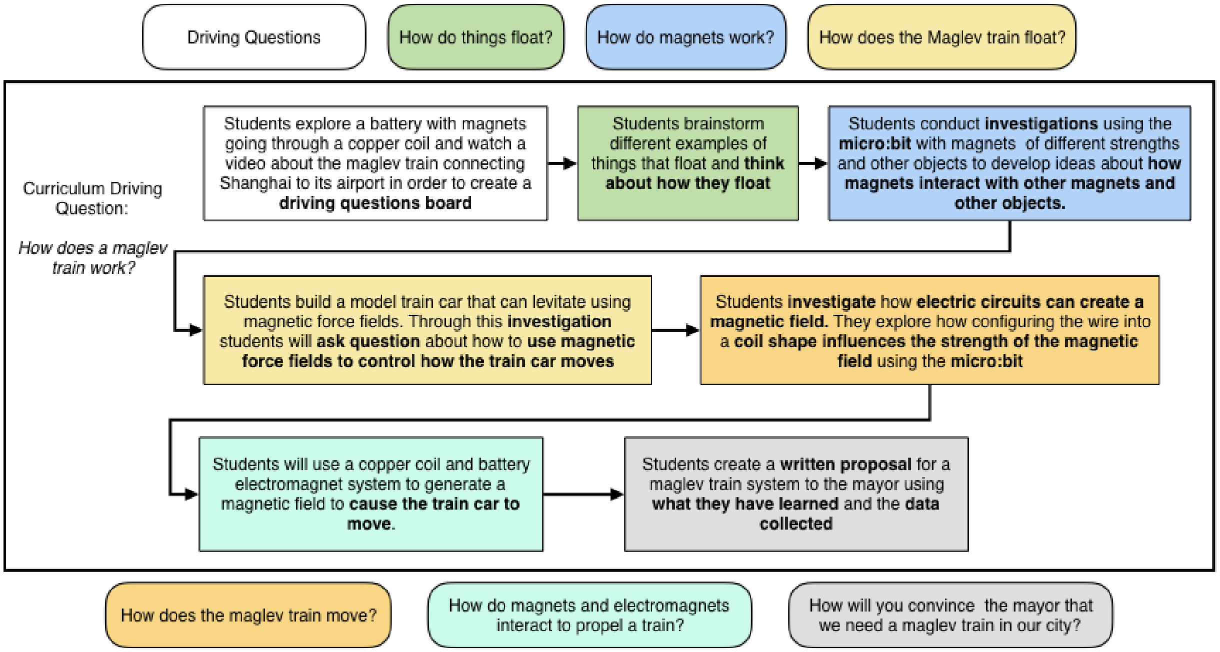
3.4.3 Design Cycle Two

The second iteration of the project began in the summer of 2018. Two teachers (one science and one integrated STEM) returned to the project. Three additional teachers, two science and one integrated STEM, joined in the second year serving a total of 488 students (see Table 3.2). The second year of the project commenced with the summer design workshop, where teachers chose between the maglev train and color-changing playground phenomena. These two phenomena garnered the top votes in a student survey developed during the last workshop of the first CT-Integration Cycle [11]. A group of teachers and researchers investigated each of the phenomena during the first day of the workshop culminating in the outline two potential storylines. Focus during the group work centered on the inclusion of three dimensional science learning, the use of the now programmable sensor technologies, and the relevance of place. The teachers determined by majority vote that they would move forward with the development of the maglev train storyline.

The investigation of a copper coil, magnet, battery system where the battery and magnet travel through the copper coil along with a video about the maglev train in Shanghai anchors the maglev train storyline, see Figure 3.5. Students learn about how maglev trains work through experiments around fixed magnets and electromagnets, which addresses the following middle school physical science performance expectations around forces and motion: MS-PS2-2: *Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object*, MS-PS2-3: *Ask questions about data to determine the factors that affect the strength of electric and magnetic forces*, MS-PS2-4: *Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects*, and MS-PS2-5: *Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.*

Students also explore what might happen if a maglev train was built in their neighborhood through research and a letter-writing activity to their community leaders to connect what they are learning to their local community.

The previous sensor technology only supported the collection of data and left most of the underlying processes hidden in a literal black box. The research team explored other options with SparkFun, eventually deciding to switch to the micro:bit, a small microcontroller designed for use in education and capable of being programmed using both block and text-based programming languages, see Figure 3.6. The micro:bit has four onboard sensors: temperature, light, accelerometer, and magnetometer. The students programmed the micro:bit using MakeCode[3] to use the magnetometer to measure the magnetic fields generated by both fixed magnets and electromagnets. The utilization of the new sensor technology supports both the Data Practices and Computational Problem Solving Practices.



Driving Questions

How do things float?

How do magnets work?

How does the Maglev train float?

Curriculum Driving Question:

How does a maglev train work?

Students explore a battery with magnets going through a copper coil and watch a video about the maglev train connecting Shanghai to its airport in order to create a **driving questions board**

Students brainstorm different examples of things that float and **think about how they float**

Students conduct **investigations** using the **micro:bit** with magnets of different strengths and other objects to develop ideas about **how magnets interact with other magnets and other objects.**

Students build a model train car that can levitate using magnetic force fields. Through this **investigation** students will **ask question** about how to **use magnetic force fields to control how the train car moves**

Students **investigate** how **electric circuits can create a magnetic field.** They explore how configuring the wire into a **coil shape influences the strength of the magnetic field** using the **micro:bit**

Students will use a copper coil and battery electromagnet system to generate a magnetic field to **cause the train car to move.**

Students create a **written proposal** for a maglev train system to the mayor using **what they have learned** and the **data collected**

How does the maglev train move?

How do magnets and electromagnets interact to propel a train?

How will you convince the mayor that we need a maglev train in our city?

Figure 3.5: Storyline of the maglev unit: How does a maglev train work? The bold text represents the science content and science and CT Practices.

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[3] An online, block-based programming environment developed by Microsoft to support programming the micro:bit along with several other physical computing devices, https://www.makecode.com

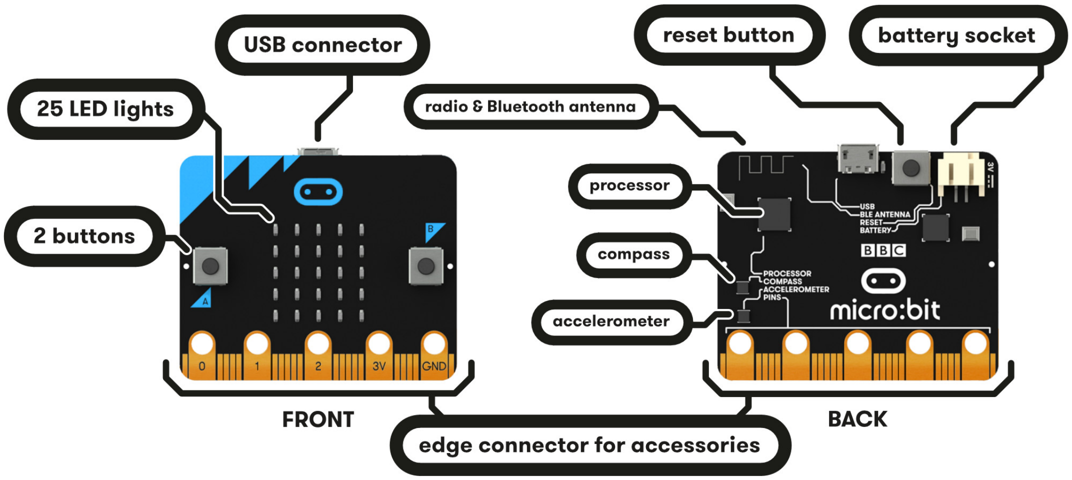


Figure 3.6: The micro:bit: the programmable sensor technology used during the second Design Cycle. Image from: https://www.amazon.com/micro-bit-BBC2546862-Micro-go/dp/B01G8X7VM2

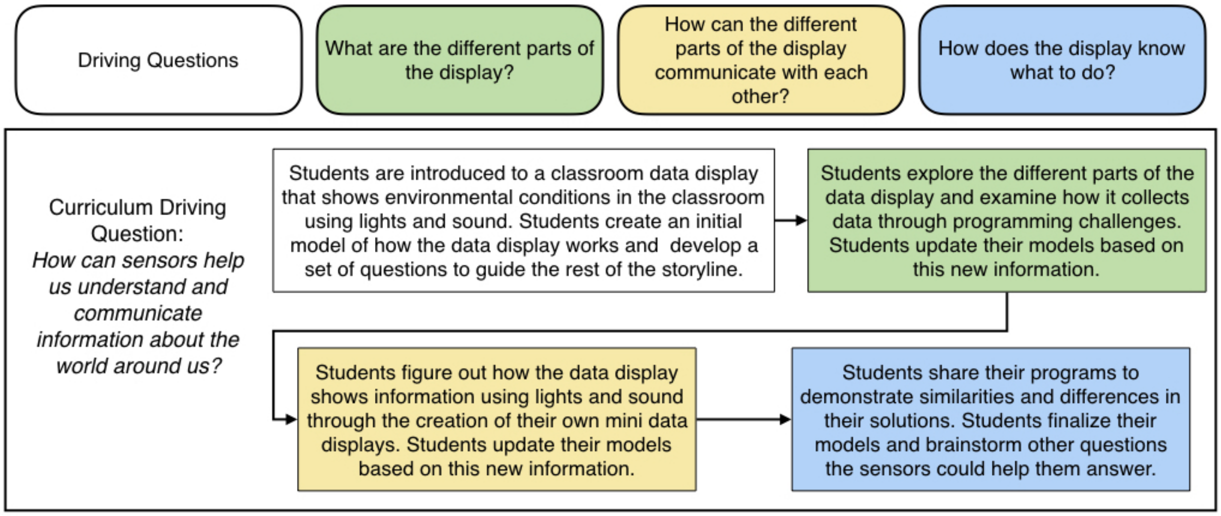
3.4.4 Design Cycle Three

For the third year, the number of teachers increased to ten, with all three science teachers from cycle two returning. One of the science teachers from the first year was out of the classroom for the 2018/2019 school year but rejoined the program for the third year. Six additional teachers joined the team: three science teachers and three Integrated STEM teachers, see Table 3.2. In total, these teachers served 971 students.

The third-year saw the development of the sensor immersion experience implemented at the beginning of the school year by all teachers to introduce students to the sensor technologies. During the first two design cycles, students wanted to use the sensor technologies but struggled to articulate why it was instrumental for their investigations. During the unit, teachers struggled to introduce the technology in a student-driven manner because students were unfamiliar with its existence and capabilities. After the unit, students struggled to describe how investigations could use the sensor technologies. The goal of the sensor immersion unit was for students to see the sensor technologies as instrumental pieces of their science toolkit. Seeing the sensor technologies as instrumental requires students to 1) articulate how the sensor technologies worked, 2) why it was useful for some scientific investigations but not others, and 3) how they could use it in future investigations.

The sensor immersion unit revolved around students investigating the use of sensors to display information about the environment around them in unique ways. A video showing wind chimes measuring air pollution in San Francisco and two classroom data displays that monitoring the environment in the classroom and classroom plant serve as the unit's anchoring phenomena. The unit addressed the middle school earth science performance expectation, MS-ESS3-3: *Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment*, through the design and creation of mini data displays by the students that illustrate information about the environment around them, see Figure 3.7 for a description of the storyline.

The sensor immersion unit utilized the expanded programmable sensor technologies through the use of the Gator:bit, which exposes additional pins on the micro:bit that allows students to use alligator clips to attach various sensors. Possible sensors include the environmental combo sensor (from Cycle 1), a sound sensor, more accurate temperature and light sensors, a particle sensor, a soil moisture sensor, and a UV light sensor, see Figure 3.8. Students can add a real-time clock and data logger that stores data on an SD card to support long term data collection.



Driving Questions

What are the different parts of the display?

How can the different parts of the display communicate with each other?

How does the display know what to do?

Curriculum Driving Question: *How can sensors help us understand and communicate information about the world around us?*

Students are introduced to a classroom data display that shows environmental conditions in the classroom using lights and sound. Students create an initial model of how the data display works and develop a set of questions to guide the rest of the storyline.

Students explore the different parts of the data display and examine how it collects data through programming challenges. Students update their models based on this new information.

Students figure out how the data display shows information using lights and sound through the creation of their own mini data displays. Students update their models based on this new information.

Students share their programs to demonstrate similarities and differences in their solutions. Students finalize their models and brainstorm other questions the sensors could help them answer.

Figure 3.7: A summary of the sensor immersion storyline

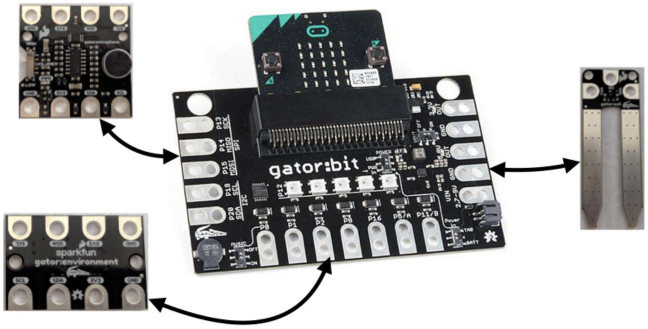


Figure 3.8: New programmable sensor technology for the third design cycle which features the micro:bit, gator:bit, and alligator clippable sensors. The sound sensor is in the top left, the environmental sensor is in the bottom left, and the soil moisture sensor on the right.

The third design cycle focused on developing an additional unit exploring how composting works and how urban composting can help residents of large cities living in food deserts grow their own food. The composting unit focuses on three middle school life science performance expectations: MS-LS2-1: *Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem*, MS-LS2-2: *Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems*, and MS-LS2-3: *Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.* The unit also supports the integration of the Data Practices and Computational Problem Solving Practices.

The compost unit centers on the concept of food deserts and lack of good soil for growing plants in the Denver area. Students investigate how to build a compost bin using vermicompost (composting using worms) and monitor different compost bins using the programmable sensor technologies to determine the ideal composting conditions. Students explore what exactly is going on as the composting process is happening through explorations of resource availability and the cycling of matter and energy. The unit concludes with students writing a letter to their principal outlining why and how their school could start an urban composting program.

A modification made during design cycle three is that teachers get to choose which unit to implement between the mold, maglev, and compost units. This allows teachers to choose a unit related to their grade-specific subject area that fits into the time they can allot to the implementation. Two teachers chose to implement the mold unit, three teachers chose to implement the maglev unit, four teachers chose to implement the compost unit, and one teacher chose to implement all the units. The implementation of these units is currently in progress.

3.5 Research Focus

This dissertation focuses on computational thinking and sensor technologies within the School-Wide Labs project. This dissertation explores how computational thinking and the use of sensor technologies evolves throughout the three design cycles. It explores students' engagement with computational thinking and the sensor technologies, teachers' understanding of computational thinking, and calls into question the very definition of computational thinking.

Chapter 4 explores how the first two design cycles integrated computational thinking and the programmable sensor technologies through an examination of the relevant components of the CT-Integration Cycle and a case study of the science and Integrated STEM teacher that participated in both iterations. The case study focuses on each teacher's experience participating in the CT-Integration cycle and their classroom implementations with special attention on how they integrated computational thinking and sensor technologies. There are two main themes or lessons learned that emerge from Chatper 4. First, the necessity and desire to include an introductory unit that allows students time to explore the sensor technology to promote its use as an instrumental scientific tool. Second, the call for a change to the definition of computational thinking in the project to support more integration of computational thinking throughout the units and not tie it specifically to the use of the programmable sensor technologies.

The need for an introductory unit based around the programmable sensor technologies led to the development of the Sensor Immersion unit. Chapter 5 describes this unit and its implementation. Chapter 5 details the design and implementation of the first version of the sensor immersion unit and discusses the results from the first implementation during the Fall of 2019. The main result is that while, anecdotally, the implementation of the sensor immersion unit motivates students to want to use the programmable sensor technologies in other scientific investigations, they lack sufficient understanding of how the technologies work. The lack of understanding prevents the students from clearly articulating and planning how they would use the programmable sensor technologies to conduct future investigations. For example, the students recognize that the environmental sensor is relevant to the mold growth unit. However, they cannot provide a detailed plan for how they would go about using the environmental sensor to collect useful information). Chapter 5 concludes with some suggested modifications for future versions of the sensor immersion unit that Chapter 7 addresses in more depth.

Lastly, the Computational Thinking in STEM Taxonomy [159] proved to be a useful framework at the beginning stages of the project. However, it became apparent during the third design cycle that the framework was not sufficient to meaningfully integrate computational thinking throughout the units, given its tool focused definitions. Although this framework language is similar to the NGSS, it still requires teachers to learn even more practices. Chapter 6 outlines the development of an expansion of the NGSS Science and Engineering Practices to include specific examples of how computational thinking can be involved in each practice in general and their specific instantiations using the sensor technologies.

Chapter 4

Lessons Learned from Design Cycle One and Design Cycle Two

The first two design cycles involve developing and refining the CT-Integration Cycle and exploring how to productively integrate programmable sensor technologies into middle school science and STEM classrooms. Several publications describe the results from the first two design cycles, including the development of the curriculum [50] and teachers' experiences within the CT-Integration Cycle [49, 48].

This chapter focuses on the sensor technology and computational thinking within the CT-Integration Cycle and classroom implementations. A conjecture map [130] guides the exploration. Conjecture maps are a tool in design based research to understand how the design of activities (embodiments) contributes to the outcomes through a set of mediating processes [130]. The mediating processes serve as design conjectures [24], whereby participating in the embodiments of the design result in the observations of the mediating processes. The outcomes represent the theoretical conjectures [24], whereby the observations of the mediating processes lead to the desired outcomes. The conjecture map provides a lens through which to put these theories in harm's way. The initial conjecture map in Figure 4.1 illustrates how programmable sensor technologies can engage middle school science students with new tools and thought processes.

The main conjecture I am investigating is that *Using programmable sensor technology in middle school science classes engages students in new scientific tools and thought processes (namely engaging in computational thinking).* Since SchoolWide Labs involves the teachers implementing the CT-Integrating units with their students, this conjecture has two desired sets of outcomes one set for the teachers (labeled OT) and one set for the students (labeled OS) as illustrated in Figure 4.1.

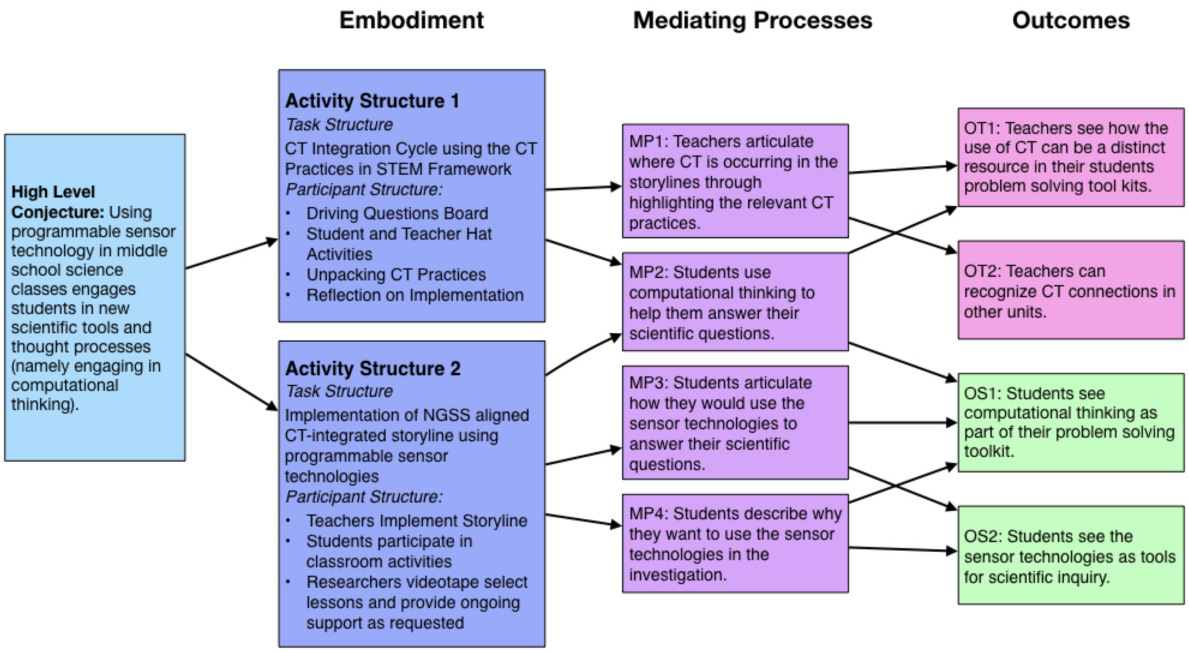


Figure 4.1: Conjecture Map for the first two design cycles focusing on the programmable sensor technology and computational thinking. Teacher outcomes are labeled OT and student outcomes are labeled OS.

These are two distinct sets of outcomes for teachers. First, teachers need to see how computational thinking is a unique way of approaching problems (OT1). That means differentiating it from other approaches such as the scientific method and the engineering design cycle. Second, to support their students' further development of computational thinking skills, teachers need to recognize opportunities for the integration of computational thinking both in the co-designed units and other units they are teaching (OT2).

The outcomes of the teachers provide support to the desired outcomes of their students.

First, students understand how the programmable sensor technologies are tools to support scientific inquiry (OS2). The goal of this outcome is for students not to see the sensors as a one-off experience more closely connected to programming and computer science than to science. Students should be able to express why and how they want to use the sensor technology and how it can help answer their questions. Students' ability to express why they are undertaking a particular activity is an essential feature of designing a coherent science curriculum [123]. The sensor technology should be seamlessly integrated into the curriculum and not require the teacher to direct the students to use sensors. Second, students should be able to use their computational thinking skills as part of their problem-solving toolkit even when not working directly with the sensors (OS1). Students engaging in the CT Practices in other units outside of those involving sensor integration would indicate success.

To investigate the specific conjecture around sensors and computational thinking, there are two tasks to explore. The first task involves teachers participating in the CT-Integration Cycle. Teachers design, adapt, and plan for the implementation of a unit that integrates computational thinking and sensor technology, followed by reflection on the implementation. While implementation is part of the CT-Integration Cycle, it is a critical piece to explore student experience, so it has its own separate task. Specific pieces of the CT-Integration Cycle are relevant to the high-level conjecture identified in Figure 4.1 as participant structures. The design of these participant structures support teachers building content knowledge around computational thinking and programmable sensor technologies as well as developing the pedagogical content knowledge around implementing science units that integrate computational thinking and sensor technologies.

The mediating processes expected in order to see to support the desired outcomes are the following:

(1) MP1: Teachers articulate where computational thinking is occurring in the storylines through highlighting specific CT practices; and,

(2) MP2: Students use computational thinking to help them answer their scientific questions.

The second activity structure involves the actual implementation of the CT-Integrated Storyline. During the unit implementation, the mediating processes expected in order to see to support the desired outcomes are the following:

(1) MP2: Students use computational thinking to help them answer their scientific questions;

(2) MP3: Students articulate how they would use the sensor technologies to answer their scientific questions;

(3) MP4: Students describe why they want to use the sensor technologies in the investigation.

Note that both Activity Structure 1 and Activity Structure 2 utilize Mediation Process 2: *Students use computational thinking to help them answer their scientific questions.* This process is shared because it depends on the successful completion of both activities. Teachers are supporting their students to engage in computational thinking thought processes, and students respond by engaging in those thought processes. Without observing these mediating processes, it is difficult to see how the desired outcomes could arise.

This chapter investigates the following two research questions to understand how these activity structures play out over the first two design cycles:

(1) What are the main lessons learned from the first two iterations of the design cycle?

(2) How do the lessons learned influence changes to the third design cycle?

Research Question One focuses on exploring how the activity structures support the mediating processes and outcomes. Research Question Two explores the modifications to the activity structures during the third design cycle based on the lessons learned during the first two design cycles.

4.1 Activity Design

This section outlines the participant structures in each activity structure. Activity Structure One revolves around the first two iterations of the CT-Integration Cycle. Activity Structure Two focuses on implementing the mold growth unit from Design Cycle One and the maglev train unit from Design Cycle Two.

4.1.1 Activity Structure 1: CT-Integration Cycle

This section provides specific details of the first two iterations of the CT-Integration Cycle that highlight computational thinking and programmable sensor technology usage. These iterations followed very similar trajectories, with the most significant difference being in the summer design workshop during the second design cycle.

These include developing a driving questions board illustrating teachers' questions about computational thinking and programmable sensor technology. Teachers also engage in portions of the storyline and programmable sensor activities using first their "student hat" and then reflecting on these activities using their "teacher hat". In order to support teachers building knowledge around computational thinking, teachers unpack the CT Practices relevant to the specific storyline. The unpacking process has proven useful in designing NGSS aligned storylines that meet performance expectations and help teachers understand what the performance expectations mean [83]. The goal was to replicate this method to help teachers better understand the CT Practices and what they look like in the classroom. Lastly, teachers engage in guided reflection around the incorporation of how computational thinking and sensor technology in the classroom implementation.

Driving Questions Board. Each design cycle began with the development of a driving questions board around computational thinking and what computational thinking looked like in STEM classrooms. This activity mirrors the conclusion of the anchoring phenomenon routine, where students develop the questions to guide the unit. Here teachers develop questions that will help guide our investigations towards understanding computational thinking. Using the driving question board in the professional development workshop models an activity that teachers will enact in the classroom and helps develop a shared learning trajectory for the workshops [160]. Like the enactments in science classrooms, this activity positions the teachers and researchers as partners in the process instead of the researchers simply providing the teachers with the knowledge of computational thinking. While the first two years do not address all the questions, the questions did help guide the design of activities for the workshops.

Each workshop is devoted to exploring these questions through different experiences around computational thinking, the CT Practices, and the sensor technology. The following strategies were useful in addressing the most pressing questions of the teachers.

"Student Hat"/"Teacher Hat". To familiarize the teachers with the different sensor technologies and computational thinking, teachers engage in a set of activities where they wear their "student hat" and then discuss the effectiveness of the activity and the role it could play in their classrooms in their "teacher hat" [80, 36]. Working in "student hat" has been an effective professional development tool when introducing teachers to unfamiliar computing concepts [55] and has also been successful in supporting the co-design of science curriculum [25, 24]. The activities are similar to activities in the classroom, so the "student hat" represents getting into the mindset of their actual students. During the first two design cycles, I served as the "teacher" during the "student hat activities". The goal for future design cycles is to transition to a teacher (or teachers) serving in this role. Teachers engaged in the "student hat"/"teacher hat" activities during other portions of the CT-Integration Cycle, specifically around the launch of the unit and the development of scientific models. However, this chapter focuses specifically on the activities related directly to the CT Practices.

Unpacking the CT Practices. To become familiar with what instruction that supports the integration of computational thinking looks like using the CT Practices, the teachers spend time "unpacking" a subset of the practices that are particularly relevant to the storyline under investigation during the CT-Integration Cycle. Unpacking the NGSS Performance Expectations [87] to draw out the focal ideas has been successful in designing and implementing NGSS aligned curriculum [83, 82]. Unpacking of the performance expectations involves taking each bullet point (of the performance expectation) and elaborating on the content and what a successful uptake of this content might look like in the classroom [83, 82]. The goal of this activity is to get teachers more familiar with the CT Practices and help them see how they connect to the storyline.

While the CT Practices are not written exactly like the NGSS performance expectations, there exists similarity in style. Instead of taking bullet points from the Performance Expectations, unpacking each sentence in the definition of the practice (e.g., Data Visualization Practice) involves breaking down the critical content pieces into that need to exist for successful implementation.

Reflection. The professional development workshop after implementation involves teachers reflecting on the implementation of the unit. The reflection process involves different aspects of the unit's design, including science standards, student engagement, the use of place, and the use of computational thinking and sensor technology. Reflection is a main component of the problem solving cycle where teachers explore via video clips [73, 17] the implementation of certain portions of the lessons. The reflection allows teachers to examine how a colleague implemented a piece of the lesson and seeds the discussion for different ways to implement the same content and strategies to go deeper into the content. Video collected from both Design Cycle One and Design Cycle two focus on lessons that highlighted the sensor technology and computational thinking practices.

4.1.2 Activity Structure 2: Classroom Implementation

The second activity structure focuses on the implementation of the unit. Implementation takes place between the second and third professional development workshops.

Teachers implement the unit in their classrooms based on the materials co-created during the first part of the CT-Integration Cycle. Teachers use the materials as a basis for implementation and are not required to follow the unit exactly. They have leeway to modify the unit as they see fit before and during implementation. Changes are encouraged and often provide ideas for revisions to the initial storyline and corresponding lessons.

Students experience the unit's implementation and engage at varying levels with the unit and the sensor technology. Since the unit is part of the regular classroom implementation, all students participate. Students have the opportunity to consent to be videotaped and interviewed during the research process, and they are aware that they are part of the research project. Teachers choose how much background detail to provide about the project.

Researchers are present to videotape selected lessons, including those that involve the use of the programmable sensor technology and that researchers anticipate will illustrate computational thinking. These lessons represent a shared experience among teachers similar to the problem solving cycle [73, 17]. Researchers are also onsite to provide technical support when requested by the teacher and are always available to provide support via email and videoconferencing. These supports are optional, but teachers are encouraged to reach out if they need or want help. While the researcher is in the classroom, it is up to the teacher's discretion to determine how they would like the researcher to participate in the classroom. Providing teachers with options for different levels of support is a conscious choice on the part of the research team to allow them to have agency in how they implement the unit and run their classrooms. The goal is for the teachers to see the researchers as partners and not as evaluation figures in their classroom.

4.2 Methodology

Descriptions of each Activity Structure and exploratory case studies [167, 10] of two teachers provide information to answer the two research questions: 1) *What are the main lessons learned from the first two iterations of the design cycle?* and 2) How do the lessons learned influence changes to the third design cycle?.

The cases offer the perspective of a science teacher, Trent, and an Integrated STEM teacher, Carolyn, who participated in both Design Cycle One and Design Cycle Two. These two cases present a way to compare and contrast teachers' experiences with different levels of expertise in science and technology instruction.

Trent is a science teacher who taught seventh grade science during Design Cycle One and eighth grade science during Design Cycle Two. Carolyn is an Integrated STEM teacher who taught grades first through eight. She implemented the units for both Design Cycle One and Design Cycle Two with her fifth graders. For information on their school and student demographics and the total number of student surveys collected, see Table 4.1.

Table 4.1: Information on the Trent, Carolyn and their students from the first two design cycles of the project. FRPL stands for free and reduced price lunch and the percentage represents the percentage of students in that school who receive free and reduced lunch.

Teacher	Design Cycle	School Demographics	Students (survey responses)	Gender	Ethnicity
Trent	1	94% FRPL	148 (110)	55% Female	94% nonwhite
	2	94% FRPL	135 (109)	47% Female	96% nonwhite
Carolyn	1	7% FRPL	90 (52)	50% Female	11% nonwhite
	2	6% FRPL	89 (30)	53% Female	20% nonwhite

Case studies involving Carolyn and Trent exist from previous analyses. This chapter organizes the case studies according to the Activity Structures. Other findings from these case studies illustrate modifications made to the CT-Integration Cycle to support teachers' design and implementation of CT-integrated units [49, 48].

4.2.1 Data Sources

There was a variety of qualitative and quantitative data collected during each design cycle from the workshops, classroom implementations, teachers, and students. All data sources are described in Table 4.2.

The goal of collecting such a wide variety of data is to have a comprehensive data set to draw on. This allows for triangulation between the qualitative data collected via interviews and video recordings and the quantitative data collected from teacher and student surveys.

For each professional development workshop, the entire day-long workshop is recorded for future analysis. During the professional development workshops, teachers take surveys to examine their current teaching practices related to the NGSS and computational thinking and their experience with programming. Lastly, partners from Utah State University who are the project evaluators, conduct focus groups, and semi-structured interviews to learn more about teachers'

Table 4.2: Data sources collected for Design Cycles One and Two. For copies of interview, survey, and reflection questions see Appendix A.

	Cycle One	Cycle Two
Teacher Interviews	Teachers partake in two 30 minute semi-structured interviews during implementation: one after the first lesson and the other after the last lesson.	Teachers partake in one 30 minute semi-structured interview after the conclusion of the maglev train storyline.
Classroom Video	Two whole classroom videos for the launch and data analysis lessons.	Four whole classroom videos two for the launch of the unit, one for the first exploration of the sensor system, and one for the introduction of electromagnets.
Student Surveys	Six SEETs that measured coherence, relevance, engagement, computational thinking practices, sensor usage, and science content knowledge. The first survey included questions on demographic information. Teachers gave at least four of the six surveys. SEETs were administered electronically.	Three SEETs that measured coherence, relevance, engagement, computational thinking practices, sensor usage. The first survey was given at the end of the launch; the second survey was given at the end of lesson 3. The last survey was given near the end of the unit, either after lesson 6 or after the unit's completion. SEETs were administered on paper.
PD Video	All four day-long professional development workshops during the school year	Summer workshop (3 days) and four day-long professional development workshops during the school year
Teacher Reflections	Written reflections based on guiding questions about the mold growth unit's implementation were collected during the third professional development workshop.	Written reflections were collected during the summer workshop and second and third professional development workshops involving preparation and experience for the maglev train unit.
Teacher Focus Groups	Conducted during every Professional Development as either a group discussion or semi-structured 20 minute interview.	Conducted during every Professional Development by using 20 minute semi-structured interviews.
Teacher Surveys	Conducted at first professional development to understand current teaching practices and CT knowledge.	Conducted at first professional development and last professional development to understand current teaching practices and CT knowledge.

experience.

During classroom implementation, researchers collect classroom videos for specific lessons during each iteration and corresponding classroom observations that note specific moments from the video. During the first two design cycles, researchers collected video from the unit's launch and two additional lessons that focused heavily on computational thinking and sensor usage. During videotaping, the camera is mostly angled at the teacher unless students are doing small group work. In this case, the researcher aims the video at a group of students who agree to appear on camera. 30 minute semi-structured interviews are conducted with teachers focusing on the unit's implementation to gauge their implementation experience and their thoughts on their students' experiences. I conducted or was present at all the interviews for Trent and Carolyn.

Student specific data is collected during implementation to help understand the student experience. As part of the curriculum, teachers collected student electronic exit tickets (SEETs) at the end of specific lessons. SEETs were developed and validated as part of the iHUB Biology effort [110, 107]. The SEETs measure student perceptions of their classroom learning experience and provide information about the student-centered instructional goals in the NGSS, namely coherence, relevance, and engagement. Prior research indicates that SEETs are useful for identifying important variations in teacher practices and classroom learning experiences. Coherence examines how well students see the lessons as a sequence of investigations and learning experiences that will help them answer the overarching driving question about the phenomenon. Relevance questions gauge whether the students feel like the material matters to them, their classmates, and their community. Lastly, we measure student engagement based on their reported responses about their interactions with the class and their classmates' interactions with the class.

In addition to the questions that query coherence, relevance, and engagement, there are specific questions about computational thinking and sensor usage to examine students' experiences with these constructs. These questions are especially relevant to this chapter's topic and help gain insight into MP3[1] and MP4[2] . The question, *Which of these helped you to program your sensor?*, asks students to select all the resources they used to program the sensor system choosing from options such as *sample code*, *trial and error*, and *your teacher or classmate.* Questions such as *I think my teacher should have us use the sensors more often to conduct investigations* and *I would recommend using the sensors to a friend if they wanted to conduct an investigation* examine if the students want to continue using the sensor technology. For a full list of the SEET questions for Design Cycle One and Design Cycle Two, see Appendix A.

4.2.2 Data Analysis

To describe the implementation of the activity structures, I reviewed the planning documents, video, and field notes from all workshops throughout Design Cycle One and Design Cycle Two. I focused on the first three workshops for Design Cycle One and the summer design workshop plus the first three workshops for Design Cycle Two. I chose not to discuss the fourth workshop of each Design Cycle because those workshops usually focused on preparing for the future design cycles and were conducted with less low-level details than the other workshops. The workshops each involved different activities taking place throughout the day. The focus of the analysis is on how the four participant structures outlined in Figure 4.1 support the teachers to engage with computational thinking, the CT Practices, and the sensor technology. These structures represent the portions of the workshops relevant to the high-level conjecture examining how programmable sensor technology can support student engagement with new tools and thought processes.

For the case studies, I reviewed the case studies we had previously created. These case studies were constructed using three stages of review: Individual work, collaboration and consensus development through small group discussion of researchers (myself included), and whole team discussion including members of Denver Public Schools and SparkFun. The SEETs and teacher surveys generate support for the interpretation of the teachers' classroom implementation, interviews, and

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[1] Students articulate how they would use the sensor technologies to answer their scientific questions.

[2] MP4: Students describe why they want to use the sensor technologies in the investigation.

written reflections. In addition to reviewing the case studies, I reread Trent and Carolyn's written reflections, reviewed critical moments of their classroom video and post-implementation interviews, and their survey data and their students' SEET data. I also read the focus group summaries created by colleagues at Utah State University. Lastly, I went back through the notes and videos from the professional development workshop to observe specifically their participation and the questions they asked. I discussed the major themes with the same small team of researchers with whom I had constructed the original case studies and shared my findings with them to reconcile any discrepancies.

4.3 Design Cycle One

The first design cycle consisted of four professional development workshops throughout the 2017/2018 school year. There was no summer design workshop due to time constraints at the beginning of the project. The sensor technology was a preprogrammed data collection box that measured the temperature, humidity, carbon dioxide, and total volatile organic compounds every second. Students transferred the data via an SD card to Google Sheets for analysis. The sensor technology did not have a student friendly interface to support any modifications to data collection. The implementation portion involved a week-long CT-Integrated unit where students learned about mold and conducted an investigation to look for the conditions for mold growth in their school using the temperature and humidity values collected by the sensor technology. For more information on Design Cycle One, see Chapter 3.4.2.

4.3.1 Activity 1: CT-Integration Cycle

This section describes the design implementation of the CT-Integration Cycle, noting what happened in each participant structure. The section concludes with the examination of Trent and Carolyn's participation in the first iteration of the CT-Integration Cycle.

4.3.1.1 Design Implementation

During the first workshop, the teachers recorded questions they had about computational thinking. The teachers and I worked together to categorize these questions into broad categories to serve as the basis for future activities. The workshops during the school year revisit these driving questions. The categories from the first design cycle were:

(1) What is computational thinking?

(2) What does computational thinking look like in the classroom?

(3) How do we determine if students are learning computational thinking?

(4) How do we teach computational thinking in conjunction with all of our other requirements?

(5) Why is data collection important?

During the first year of the project, the focus was mainly on the first two questions by learning about the CT Practices, sensor technology, and integrating these pieces into the mold growth storyline and lessons. Researchers selected the first two questions to tackle first because, without understanding computational thinking, it is difficult to investigate the other three questions. The discussion of storyline implementation touched on questions four and five, with teachers expressing that the use of the programmable sensor technology did not take away from students' science learning. The students also developed a new appreciation for the ease with which the sensor technology collected large amounts of data. Question three required a more in-depth understanding of the first two questions.

During the first and second workshops of the first design cycle, the teachers experienced the data collection and analysis portion of the storyline while wearing their "student hats". The teachers collected data using the preprogrammed sensor system. They analyzed both this data and data I had collected from different places in my house to generate visualizations and explanations for the likelihood of mold growth. The analysis and visualizations took place in Google Sheets, a graphing tool available to all the students. The main goal of this activity was to familiarize the teachers with analyzing data sets with upwards of 1000 data points and to see what supports and scaffolds would be useful for their students. Teachers expressed how easy it was to collect data but were concerned about supporting their students using Google Sheets with such large amounts of data. They discussed several options to support their students, such as modeling how to use Google Sheets to hide columns of data and create graphs.

The first design cycle focused on Data Practices [159] because they served as a familiar entry point for the teachers, and the first version of the sensor technology supported them. During the second professional development workshop, teachers worked in two groups supported by researchers to unpack the Analyzing Data and Visualizing Data Practices. The mold growth unit highlights these practices, and the teachers had just experienced these activities from a "student hat" perspective.

For example, the Visualizing Data Practice states that: **In mathematics and science, creating visualizations is a powerful strategy for both analyzing and sharing data** [159], which the teachers unpacked into the following two statements: 1) *What is the difference between a visualization that's good for analysis and one that is is good for communication?* and 2) *You can discover new things with visualizations and use them for communication.* Here, the teachers express the importance of different kinds of visualizations depending on the goal of the visualization and illustrate how visualizations can provide new insights into the data. The last sentence of the Visualizing Practice: **Students who have mastered this practice will be able to use computational tools to produce visualizations that convey information gathered during analysis** [159] further explicates this. The teachers described it as *Visualization needs to be "useful" to address a driving question, not just any visualization.* This practice is highlighted in the mold growth unit when students have to argue whether or not their school has the conditions to support mold growth.

During the reflection for the mold growth unit, one video illustrated how a teacher used videos she created, describing how to use Google Sheets to organize the data collected to scaffold independent data analysis. The second video illustrated how one teacher used the data analysis and visualizations to write a letter to the principal, arguing whether the school should shut down due to mold growth conditions. Each discussion began with the teacher in the video explaining what they had done and why. The main discussion around the first video involved determining the right amount of scaffolding necessary to support students' use of the Data Analysis and Data Visualization Practices. Some teachers thought the video was appropriate given the level of student experience, while others worried that it could overscaffold them. For the letter-writing culminating activity, the teachers examined *How might CT practices, specifically data analysis and data visualizations, be more deeply utilized and supported in a culminating activity like this?*. This examination led to a discussion about how to use data visualizations to support an argument from evidence and the role that place played in the process.

4.3.1.2 Case Studies

This section presents case studies of Trent and Carolyn during their participation in Activity Structure One (the first iteration of the CT-Integration Cycle).

Through the Eyes of a Science Teacher: A Case Study of Trent. During the first design cycle, in a survey given during the first workshop, one of Trent's goals was to support his students in engaging in science in ways more similar to those of real scientists. One of the ways he saw to do that was through the adoption of novel technologies. He did not have prior experience in programming and sensors, but he did feel reasonably confident that he could support his students in the CT Data Practices. Although Trent felt that he did not fully understand computational thinking, he was excited to learn more about it and incorporate sensor technology into his instruction.

During the first professional development workshop, Trent questioned how computational thinking differed from other processes he was already teaching to his students, such as the scientific method and critical thinking. Trent would voice this question throughout the other professional development workshops. Throughout the first design cycle, Trent associated computational thinking only with engagement with CT Data Practices [159]. For example, during the second professional development workshop, when asked about what he learned about computational thinking, Trent stated that "the main thing can be visualization, and to get past the data and the numbers and instead to analyze it."

After the classroom implementation, Trent remarked that he was satisfied with his students' use of the sensors. He felt that his students got "to use different tools to allow them to see themselves as scientists." However, Trent would have preferred students to experience an introduction to the sensor technology before the mold growth unit. He stated: "I wish I would have had… a day or two for the kids to have the sensors in their hands and come play around with them and get used to them. So that when we go around the school and look for mold, it's not their first time doing that." Trent explained that if the students had prior familiarity with the sensors, they would have been more likely to come up with the idea of using the technology themselves. They would have been more capable of independently retrieving data from the SD card.

In a written reflection, Trent responded that the unit was a good entry into computational thinking for his students, "but my emphasis wasn't on the data as much due to time." Trent felt that it was important to allow his students to construct graphs from their sensor data to interpret and make sense of the data they collected. However, due to time constraints, he felt that the data analysis had to be heavily scaffolded and was unsure if his students would be able to independently engage in a similar analysis.

Trent noted that his students were clearly engaged in computational thinking when they compared their own humidity and temperature data with the ideal conditions for mold growth that they had figured out earlier in the unit. Trent reported, "I guess that to me it is the computational thinking side of it. They're comparing their data to those rankings, so I think that's what was leading them to those conclusions." Although it was disappointing to his students that none of them found mold in their school, Trent was satisfied with the unit's computational thinking elements and the focus on sensemaking.

His follow up interview and written reflections show how Trent is associating computational thinking with data collection and analysis, albeit on a larger scale than his students had previously experienced. He views the primary goal of the project as getting "kids used to use different tools to allow them to see themselves as scientists."

Through the Eyes of an Integrated STEM Teacher: A Case Study of Carolyn. Carolyn was the only Integrated STEM teacher during the Design Cycle One. As an integrated STEM teacher working in a K-8 school, her lessons typically focused mostly on technology and engineering. She had taught a variety of programming languages to her students and previously incorporated robots that included sensors in her Integrated STEM classes. When asked how she wanted to grow her science teaching, Carolyn responded that she wanted to learn more about incorporating sensors as scientific tools and "how to provide foundational programming skills for students."

Carolyn was particularly interested in measuring computational thinking and understanding if and to what extent her students engaged in the process. She had engaged in previous professional development experiences around computational thinking and computer science with her initial understanding of computational thinking expressed as "Breaking down problems to solve". In contrast to Trent, she saw computational thinking as a distinct thought process related to the Computational Problem Solving Practices [159] and more than enhanced data analysis.

Carolyn also wanted her students to be aware of when they were engaging in computational thinking, reflecting during the second professional development workshop that "we can use the name, but students need comfort and familiarity with these concepts and terminology and how it is empowering." To support her students' independence, Carolyn's preferred style of teaching is through small group projects at different stations around the classroom. At the end of each lesson, students come together as a class to discuss the challenges and successes they had throughout the class period and look to see similarities in their projects.

During the reflection workshop, Carolyn shared her rationale for creating the videos to support independent data analysis and discussed additional ways to scaffold the data analysis, such as using data that was similar to but not identical to the data the students collected to prevent overscaffolding. She also spoke in detail about how her students had spent an entire class period engaging in the data analysis through “looking for patterns, graphing and filtering data that did not pertain to their driving questions.”

Summary. Trent and Carolyn began the project with different goals and ideas about computational thinking. Trent focused on getting new tools for science investigations in the hands of his students. At the same time, Carolyn was more concerned with helping her students grow as computational thinkers and enhance their programming abilities. She recognized computational thinking as a unique thought process, while Trent did not think that it represented a new way of thinking. This difference is clear in the language that they use to describe how their students engage with the CT Practices. These goals manifested themselves in their reflections on the classroom implementation, where Trent highlighted his students’ ability to use a visualization to create an argument from evidence. In contrast, Carolyn spent more time discussing how her students engaged in the data analysis and the creation of the data visualizations.

4.3.2 Activity 2: Classroom Implementation

This section discusses the classroom implementation of the mold growth unit. It begins with a short description of the unit and concludes with Trent and Carolyn’s experiences implementing the unit in their classrooms, focusing primarily on their students’ experiences.

4.3.2.1 Design Implementation

The mold growth storyline followed the creation of an investigation where students searched their school for the ideal conditions for mold growth using a custom-built preprogrammed sensor technology. Teachers had the storyline, an outline of the anchoring phenomena routine, student activity sheets, readings on mold growth, and data collected using the sensor technology to support the readings. Teachers could choose a culminating activity for their students and modify any existing pieces to fit their classroom needs and teaching style. This included where students were allowed to search for mold growth conditions with some teachers allowing their students to explore the entire school while others had their students remain in the classroom.

Students engaged in the CT Data Practices to collect, manipulate, analyze, and visualize the data to support an argument based on this evidence whether or not their school had the conditions for mold growth.

Researchers were present during the anchoring phenomenon routine and the data analysis portion. Teachers could request a researcher in the classroom for the data collection lesson that used the sensor technology. Trent and Carolyn, along with one other teacher, requested that a researcher be present during data collection.

4.3.2.2 Case Studies

Through the Eyes of a Science Teacher: A Case Study of Trent. Trent spent a full week implementing the mold growth unit with his students, staying close to activities outlined in the storyline. In an interview afterward, Trent stated that he could have used three weeks to implement the lessons, particularly if it had been part of his larger ecology unit. However, due to the limited amount of time, Trent decided to control certain aspects of his students' sensor use, for example, by taking the students' SD cards out of the sensors and putting the cards into their computers to download the data. Trent was concerned that his students would not be able to do this particular action on their own without either breaking the equipment or running into other problems that would require troubleshooting and lost time.

Trent felt that the unit helped his students gain an appreciation for quickly and easily collecting using sensors, analyzing the results, and interpreting a large data set. The majority of Trent's students expressed that using the sensor system was easy (66%) and fun (54%). About 20% of Trent's students found the sensors confusing, but few indicated that working with them was frustrating or hard. Also, 82% of Trent's students reported that they wanted to use sensor systems more often to conduct investigations.

The students' survey data supported Trent's impressions of his students' engagement and perceptions of relevance. Further, over 40% of his students felt "excited" about their classroom activities. In general, Trent's students used mostly positive adjectives to describe how they felt about the lessons, including 24% who felt like scientists while engaging in the activities. However, 20% reported feeling confused - similar to the percentage of students who described the sensor system as confusing.

An adaptation that Trent made to the storyline was to direct his students to write a letter to the principal based on the results of their mold investigation. The letters must include a convincing argument about whether their school should be closed if there was mold in their school. The argument had to include information on the sensor technology and data analysis they had performed. For example, the students could predict what might happen to create a situation favorable for mold growth, such as a pipe bursting or a leaky air conditioner. Trent personally found the question of when a school should be "shut down" intriguing and was confident it would resonate with his students. Trent explained, "That's to me how you can be a good teacher. You have to be a storyteller and have some sort of story that is attractive to kids."

Through the Eyes of an Integrated STEM Teacher: A Case Study of Carolyn. During implementation, Carolyn allowed her students to use the sensors somewhat more independently compared to Trent. However, anticipating that they might struggle with analyzing the large amount of data collected by the sensors, Carolyn decided to create a series of short instructional videos for her students. The videos walked them through several data practices - such as how to hide data, set up x and y axes, and generate graphs. After students viewed the videos independently or in small groups, most were able to use a spreadsheet to organize, analyze, and visualize their data with minimal guidance. Carolyn had created similar videos for her students in the past and found them to be effective teaching aid that supported productive, independent work. Since the students had a clear sense of how to work with their data, they generally stayed on task and dug deeply into data analyses and sensemaking. Carolyn shared these videos with Trent and the other teachers, all of whom used them in their classrooms to support students' organization of the data they collected.

Like Trent, Carolyn felt her students were empowered by looking at the data they collected about mold growth in their school and by being asked to make decisions about what to do next. Carolyn noted that her students retained their interest in the mold unit even after it concluded. They were especially interested in using the sensors as part of an ongoing study of the more likely locations for mold growth. The survey data support Carolyn's intuitions, with most of her students reporting that the sensors were fun (85%) and easy to use (53%). These data are similar to those collected from Trent's students, although somewhat more of Carolyn's students found the sensors "fun," and somewhat fewer found them "easy". Like Trent's students, a sizable portion of Carolyn's students (24%) found the sensor system confusing. Carolyn's students were somewhat less enthusiastic than Trent's students in their desire to use the sensors for future investigations, with about two thirds (64%) responding that their teacher should have them use sensors more often during class.

Carolyn instructed her students to explain why mold could grow at given locations within their school, supported with a visualization based on their data, and recommend what should be done to either eliminate or prevent mold growth in the future. As they considered their data, Carolyn's students actively engaged in small group discussions about the pros and cons of different types of graphs, thought carefully about which data was most useful for their purposes, and inspected the labels automatically generated by the spreadsheet for accuracy. Carolyn noted, "We had discussions about how scale can make things look more dramatic. The data was fairly consistent; they could make it look like it was climbing by making the scale (range) small enough."

In contrast to Trent's students, Carolyn's students found mold growing in some places in their school. Discovering mold and learning computational practices for interpreting big data sets they personally collected, appeared to help Carolyn's students feel a sense of ownership throughout the unit. Carolyn explains, "I think they were empowered because they were looking at data that they had collected and making some decisions and then thinking about what's next." Carolyn's students' generated recommendations for preventing mold growth, such as "we should get ventilators for the boiler room to circulate moisture." Some of Carolyn's students later spoke with local stakeholders (including the principal, facilities manager, and food services manager) about where the mold was in their school and how to prevent mold growth. They even offered to continue to monitor those locations in the future.

In a written reflection, she responded, “I was skeptical about how this unit would be received in my classroom (as my classroom is typically based on student choice), but students were thoroughly engaged and curious throughout the project.” She elaborated that the lessons were “filled with student-driven problem solving” and “the use of sensors in the classroom made students feel like they were *doing science*.” The data from the SEETs supported this conclusion, where on average, 70% of the students reported feeling “excited” and “like scientists”. Like Trent’s students, relatively few of Carolyn’s students used negative descriptors to convey their feelings about the lessons, although some (11%) did report feeling confused.

Summary. Trent and Carolyn both perceived their implementation of the unit as a success. Trent grounded the unit in a classwide investigation to get an extra week of spring break by finding the conditions for mold growth and arguing to the principal using the analyses and visualizations created by the students from the data collected using the sensor technology. This drew heavily on the school’s relevance to the students, and students were exceptionally engaged in the process even though they did not find the conditions for mold growth. While Trent’s students did not engage in the in-depth discussions around data analysis and data visualizations that Carolyn’s students did, they did see the use of the practices in engaging in an argument from evidence.

Carolyn, on the other hand, did not emphasize place to the same extent as Trent did, but her students found mold growing in their school. They found this very exciting and took it upon themselves to connect with local stakeholders to address the mold and volunteered to continue monitoring the situation. Carolyn engaged her students in productive conversations around the data practices through questions that asked them to explain their analysis choices and data visualization.

4.4 Design Cycle Two

The second design cycle consisted of a three-day summer design workshop before the 2018/2019 school year and four professional development workshops throughout the school year. During the summer design workshop, teachers chose to design a storyline around how maglev trains worked that explored both fixed and electromagnets. Due to lack of student control, the custom-built sensor technology from the first design cycle was dropped in favor of working with the micro:bit, a microcontroller with several onboard sensors including a magnetometer designed for use in the classroom. Students can program the data collection using MakeCode, a block-based interface developed by Microsoft. For more information on Design Cycle Two, see Chapter 3.4.3.

4.4.1 Activity 1: CT-Integration Cycle

This section describes the design implementation of the CT-Integration Cycle, noting what happened in each participant structure, focusing on the teacher outcomes. The section concludes with the examination of Trent and Carolyn's participation in the second iteration of the CT-Integration Cycle.

4.4.1.1 Design Implementation

The second design cycle began similarly to the first design cycle with the creation of a computational thinking driving questions board. For this cycle, in addition to categorizing the questions as a group, questions were also prioritized as a group instead of by the researchers. The categories of questions are listed below.

(1) How can we develop a shared vocabulary around computational thinking?

(2) What does computational thinking look like in the classroom?

(3) What does computational thinking look like in our current curriculum and the storylines we are creating?

(4) What are some possible vertical trajectories for our students learning of computational thinking?

(5) How can we support English Language Learners?

The broad categories of questions are similar to Design Cycle One to Design Cycle Two. For example, the first question is similar to the first question from the first year, *What is computational thinking?*, although it has increased in specificity through the focus on a shared vocabulary instead of a general definition. The second, third, and fourth questions correspond to the second question from the first year, *What does computational thinking look like in the classroom?* with the third and fourth questions looking for more concrete examples around ways of computational thinking presents itself in the classroom and over time. The question of vertical integration also relates to the third question from the first year, *How do we determine if students are learning computational thinking?* The teachers want to know potential trajectories for students to follow as students advance in their computational thinking knowledge. The teachers chose to star with the first question and to explore questions two and three during the planning and reflection workshops. To support English Language Learners (mostly Spanish speakers in Denver Public Schools), the teachers suggested providing as much of the material as possible in Spanish and designing instructional scaffolds that did not require students to speak or read English, such as video tutorials.

The second design cycle's summer workshop introduced the micro:bit and block programming as the second version of the sensor technology using the "student hat"/"teacher hat" strategy. Teachers participated in both introductory programming and debugging activities, along with the programming activities they will implement in the storyline. First, teachers worked in small groups to program the micro:bit to scroll their name in the LED lights and created a rock, paper, and scissors game. These activities introduced teachers to the MakeCode Interface and the micro:bit. Then they explored the different sensors available on the micro:bit: temperature, light, accelerometer, and magnetometer. During the first and second workshops, teachers participated in the first lesson that uses the micro:bit to collect data about fixed magnets to develop a quantitative model of a magnetic field. Like the first design cycle, the goals of these activities were to familiarize the teachers with the sensor technology and see what supports and scaffolds would be useful for their students. Scaffolds suggested include whole classroom demonstrations, video tutorials, and free time for students to explore the capabilities of the micro:bit. Teachers also discussed how best to introduce the micro:bit and magnetometer to their students.

For the maglev train storyline, the planning workshops revisit the Data Practices unpacked during the first cycle and introduce the Computational Problem Solving Practices. The second version of the sensor technology required students to program the data collection instead of having the system preprogrammed for them. The introduction of programmable tools directly relates to the Computational Problem Solving Practices, focusing on when and how to use computational tools to help in scientific investigations. While much of the content in the Data Practices was familiar to teachers, the Computational Problem Solving Practices represent mostly new content. Again, after engaging in activities in their "student hat", teachers worked in small groups to read through and add to the Computational Problem Solving Practices' initial unpacking completed by the research team. For the Programming task, the teachers focused on the different levels of mastery using a beginning, intermediate, and advanced rubric. An example of a progression they created is beginning: *give specific directions in order "How to" style*, intermediate: *modify existing programs*, and advanced: *write a program to automate a task*. For the Troubleshooting and Debugging task, the teachers divided the practice into things their students could say or things they could ask the students and what they would do in response. For example, a student might *say* "What can I change to figure out where my program isn't *working*" and then what the students should *do* by identifying a variable to change and determining how it affects the outcome. Students creating small programs to collect the strength of different magnetic fields around both fixed and electromagnets represent the computational problem solving practices. Students mostly remain at the intermediary step of modifying existing programs.

For the maglev train reflection workshops, the focus was on how the teachers introduced the sensors. The first video focused on the necessity of collecting quantitative data about the magnetic fields. This discussion centered students observing other phenomena both physically (or qualitatively) and numerically (quantitatively). For example, students feel changes in temperature, but degrees Fahrenheit also represents temperature. After watching the first video, the teachers discussed how their transitions compared and how they tried to make the transition to quantitative data collection student-driven. Getting the students to want to use the micro:bit to measure the magnetic field required significant teacher direction because they were unfamiliar with the tools. They did not understand why viewing the magnetic field with the iron filings did not provide enough information to answers their questions.

The second video described how a teacher introduced the necessity to program the micro:bit to her class as collecting the quantitative data they needed. She made the analogy about how the micro:bit spoke its own language and that to get the micro:bit to measure the magnetic fields, students would have to learn the language of the micro:bit. Her language analogy resonated with her students because she worked at a refugee school where students speak various languages. The discussion after the second video focused on how teachers introduced the micro:bits and programming in their classrooms. Some teachers had engaged in discussion around the purposes of programs while other teachers simply told the students that the micro:bit needed to be “coded” to work. These discussions culminated in a discussion around how to expose students to sensors and other tools in ways that help them internalize their functionality.

4.4.1.2 Case Studies

Through the Eyes of a Science Teacher: A Case Study of Trent. During the summer design workshop, Trent stated that one of his goals for the year was to learn “more about programming so I can better assist and teach my students how to use the sensors”. The fact that the micro:bit required students to program their own data collection as opposed to using a system that was already programmed was a big concern throughout the workshop and in his post-workshop reflections. “Perhaps, my question is truly, how much time will I need to spend with my students to teach them this? Or do I even need them to know how to code the micro: bit, do I set it up for them?”

His concerns remained throughout the first two workshops before implementation. In the second workshop, he stated that his “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.”

Trent received additional support to support his students’ use and understanding of the micro:bits. His students explored the different sensors available on the micro:bit and some ways to collect and display data during a one-day introduction to the sensor technology. The students interacted with preprogrammed micro:bits. A laptop at each station displayed the code. There was a station where the accelerometer lit up a strip of LEDs based on how fast it was accelerating, a station that had magnet detectors (an LED picture on the micro:bit that got brighter the stronger the magnetic field), and a station that displayed the temperature using a graph. Trent’s goal for this introductory experience was for his students to see the block programming and better understand the micro:bit’s capabilities so that the use of the micro:bit would be driven more by his students during the maglev train unit.

While Trent improved his understanding of the CT Data Practices and Computational Problem Solving Practices, he still struggled to see what made computational thinking unique. After completing several programming activities with the micro:bit, he reflected that “the primary way I see CT represented is through computational problem solving practices. I needed to think critically to solve how my computer can tell the micro:bit what I want it to do using the block coding platform on the micro:bit’s website.” This quote shows how he is still conflating the ideas of computational thinking with critical thinking and how computational thinking must involve the use of data: “the major aspect of CT I didn’t see is the use of data”.

During the reflection workshop, Trent argued that the maglev train unit represented a good introductory unit for CT, but would like to see the development of additional units that delved more deeply into the usage of sensors and computational thinking.

Understanding the different aspects of computational thinking still presents a challenge for him. While he expanded his definition to include both the use of the data practices and programming, he still struggled with the why of using the sensors. “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." He would appreciate "starting at a lower level, breaking down the different blocks that go into programming before needing to build one and explain what I am doing and why."

Through the Eyes of an Integrated STEM Teacher: A Case Study of Carolyn. During the second design cycle, Carolyn's goal was to "learn more about CT - be able to communicate that to students, parents, and colleagues". She was very excited about the micro:bit and thought it would provide students with more opportunities to customize the data collection, data analysis, and data visualization processes to support a more extensive set of CT Practices.

She wanted to grow her understanding of the computational thinking practices "to be able to name the CT practices and use them more fluently throughout classroom discussions." Also, she wanted to explore the progression of computational thinking throughout the grade levels. In a written reflection at the summer design workshop, she remarked that she was "very curious as to how this looks at various grades - how do we help students to think computationally (is that a word) in 1st grade? 2nd grade?...and on through the middle grades. How do we manufacture engaging computational thinking experiences for students of all grade levels. What experiences have students already had that require computational thinking?"

During the professional development workshops before implementation, Carolyn provided support for other teachers during the lessons around programming and data collection. During the "student hat" activities, she helped teachers who were struggling by suggesting different ways to approach the problem. One of the key computational thinking elements she observed throughout the "student hat"/"teacher hat" activities was "writing simple programs including logic/loops/structures, choosing the most effective way to solve a problem, thinking systematically to provide all the possible solutions to the problem."

Several teachers expressed concern about the ability of both themselves and their students to program the micro:bits to collect data successfully. Carolyn offered her own classroom experiences undertaking similar exercises to help alleviate the uncertainty. She encouraged the teachers to become comfortable with a little chaos and not knowing all the answers.

During the reflection workshop, while Carolyn found the unit to be an adequate introduction to the micro:bits, she expressed her desire for students to have time to explore the sensor technology more. "I want more quick programming experiences early in the unit, and more open-ended programming experiences later in the unit." This represented a similar sentiment to Trent and was a significant reason he wanted the students to participate in an introductory activity involving the micro:bit before the start of the maglev train unit. In the future, Carolyn would "encourage giving students time to "play" with the micro:bit before diving into the data collection."

Summary. Trent continues to struggle with understanding computational thinking but has expanded his definition beyond the use of data. Carolyn continues to ask detailed questions around computational thinking, but the project struggles to support her and other, more advanced teachers to build their knowledge. Both Trent and Carolyn expressed interest in activities where their students explore the functionality and potential uses of the programmable sensor technology. The goals of these activities would be for students to 1) internalize the functionality of the programmable sensor technology and 2) determine the different ways to use it in their scientific investigations so that students articulate how using it will help them answer their questions during the subsequent unit.

4.4.2 Activity 2: Classroom Implementation

This section discusses the classroom implementation of the maglev train unit. It begins with a short description of the unit. It concludes with Trent and Carolyn's experiences implementing the unit in their classrooms, focusing on the student outcome 1[3] and student outcome 2[4] .

4.4.2.1 Design Impementation

The maglev train storyline revolves around students figuring out how a maglev train worked by investigating fixed and electromagnets. The magnetometer on the micro:bit allows for collecting quantitative data around the strength of the magnetic field. This quantitative data provides numerical information in support of the qualitative magnetic field images created using iron filings. The magnetometer can also measure the magnetic strength of electromagnetic fields. Teachers received significantly more resources to guide the implementation of the maglev train unit as opposed to the mold growth unit, including teacher guides and slide decks for each lesson to complement the storyline and student activity sheets. Teachers still had the option to modify any existing pieces to fit their classrooms, but no specific curriculum pieces were left open-ended.

Students engaged in Computational Problem Solving Practices and Data Practices as they programmed the micro:bit to collect magnetic fields' strength.

Researchers were present during the anchoring phenomena routine, during the first use of the micro:bit, and during one of the electromagnet lessons where students used the micro:bit to measure the strength of electromagnetic fields. The researcher's role in the classroom was up to the teacher with most teachers, including Trent and Carolyn, using the researcher to assist students with programming the micro:bit.

4.4.2.2 Case Studies

Through the Eyes of a Science Teacher: A Case Study of Trent. Trent implemented the maglev train unit over three weeks in January 2019. He was the first teacher to implement the unit. Thus most of the issues with the curriculum were fixed during his implementation. Trent's students were able to generate many questions about the maglev train and coil/battery train that drove the unit's first three lessons. However, when it came time for the students to transition from viewing

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[3] Students see computational thinking as part of their problem-solving toolkit.

[4] Students see the sensor technologies as tools for scientific inquiry.

the magnetic field using iron filings to collecting quantitative data around the magnetic field, they struggled to come up with why they needed to know numerical information about the magnetic field. Once they wanted to measure the magnetic field numerically, they did not immediately see the micro:bit as a tool that could help them even though they had used the micro:bits previously. Trent left the micro:bits out on a table in the front of the room. Trent had to explain to his students why they should use the micro:bit to help them understand magnetism.

Once the students started using the micro:bit, Trent remarked that “the sensor allowed students to *see something that was invisible* by assigning a measurement to the magnetic field around magnets and the copper coil electromagnet.” This helped the students better understand what they had seen with the iron filings. The magnetometer is not physically centered on the micro:bit, so the values of the strength of the magnetic field do appear symmetric, whereas the iron filings make the magnetic field appear symmetric. This “made for a discussion about the data - knowing the location of the sensor now, we can adjust in the future how to orient the micro:bit.” This discussion comes up often when using new scientific instruments as scientists become more accustomed to their particular workings.

Overall the students enjoyed using the sensors, and 82% of them wanted to use the sensors again in future investigations. 56% felt confident that they could program the sensor to answer other scientific questions. Students relied on the teacher (60%) and classmates (34%) the most for help during the actual programming portion. Trent expressed that he “would also like to see the micro:bit used more in the unit” and missed the aspect of large scale data collection and analysis that was present in the mold growth unit. He was not sure how to integrate these aspects but hoped that a future revision would explore these issues.

Throughout the unit, the students engaged in activities to understand fixed and electromagnets using sensors and other means of investigation. Throughout the unit, approximately 45% of students felt like a scientist, almost double the percentage of students during his implementation of the mold growth unit.

Through the Eyes of an Integrated STEM Teacher: A Case Study of Carolyn. Carolyn was concerned about implementing such a long unit in her fifth grade classroom. Most of her units went a maximum of two weeks, and the maglev train storyline takes at least three weeks. To make matters more complicated, she only saw one-third of her students each week, so the entire unit could take up to nine weeks to implement to all of her students.

Like Trent's students, Carolyn's students were able to come up with a series of questions to drive the investigations in the unit related to the maglev train and coil/battery train system. While her students had used the micro:bits before, most were not familiar with the fact that the micro:bit could measure the strength of magnetic fields. Without this previous knowledge, it was challenging for her students to come up with the fact that they wanted to use the micro:bit to measure the strength of the magnetic fields. Carolyn anticipated this challenge and led a class discussion around the need for numerical measurements to understand better the qualitative data the students are seeing. She used analogies between the iron filings and the weather reports to get students to think about how they might better understand what the iron filings represented. Once she seeded the idea for collecting quantitative values for the magnetic field in her students' minds, she brought out the micro:bit as a tool to generate those numerical values.

Overall, Carolyn's students enjoyed using the sensors, with 66% wanting to use them again in the future. Carolyn's students were more confident in their ability to program the sensor to pursue another investigation, with 96% answering in the affirmative. Similar to Trent, the students relied most heavily on their teacher(80%) and classmates (42%). However, (38%) relied on trial and error as opposed to only 11% of Trent's students.

Like Trent's students, Carolyn's students struggled with the inconsistencies due to a lack of symmetry in the strength of the magnetic fields. She remarked that "this was difficult for some students to get past." However, throughout the entire unit, over 90% of Carolyn's students felt like scientists almost 20% more than during the mold growth unit.

Summary. The students did not articulate why they would use the micro:bit to measure magnetism without significant prompting from Trent and Carolyn. Although Carolyn was somewhat more successful by creating analogies to other "invisible" phenomena that are measured, the Trent and Carolyn provided most of the rationale for using the micro:bit. Neither Carolyn nor Trent highlighted the place-based aspects of the maglev train unit. Both teachers omitted the last lesson of the unit, where students explored what would happen if a maglev train was built in their neighborhood.

4.5 Discussion

This section presents the lessons learned based on the findings from the first two design cycles (RQ1) that leads to the creation of a modified conjecture map representing the changes for Design Cycle Three (RQ2).

Research Question 1: *What are the main lessons learned from the first two iterations of the design cycle?*

Four main lessons learned emerged from the analysis of the first two design cycles: (1) Teachers equate computational thinking with the usage of the sensor technology, (2) Teachers struggle to understand computational thinking as a distinct approach to problem-solving, (3) Since teachers do not understand how to apply computational thinking outside of the use the sensor technology, students may also develop this misconception, and (4) The usage of the sensor technology is not driven by the students.

Teachers state that their students are engaging in computational thinking when they use the sensor technology. They do not think other portions of the storyline include computational thinking. I observe this in discussions about where they see computational thinking represented in the storyline. Teachers can quickly call out the portions of the unit that use the sensor technology and analyze data. However, they often say that no computational thinking is present during other lessons in the unit. This leaves large portions of the unit, where teachers are not highlighting computational thinking. Thus I am not observing mediating process MP1[5] .

Computational thinking is more than just using computational tools; it is a problem-solving approach that utilizes concepts from computer science [166, 8]. For the teachers, the association of the sensor technology and computational thinking conflates the use of the tools with an approach to problem solving. Simply engaging with the tools does not guarantee that students are engaging in activities that require computational thinking. For example, completing a program with all the blocks preselected does not require them to understand anything besides assembling the blocks like a puzzle. They do not necessarily need to understand what the blocks are doing or why they are assembling them in a particular pattern. Students can engage in computational thinking without using the tools. For example, reframing questions to be more specific or physically engaging in the simulation of a computational model [117] are both examples of computational thinking that do not rely on computational tools.

Some teachers, especially the science teachers, do not see computational thinking as a distinct resource (Teacher Outcome 1) and have trouble differentiating it from critical thinking and the scientific method. For example, Trent has struggled with this idea for two years, as expressed through the questions he posed around computational thinking and how it represents a unique approach to problem solving. The CT Practices [159] focus on the usage of computational tools to promote computational thinking and do not delve into how it represents a distinct problem solving approach. While the CT Practices framework provided a good entry point for teachers to think about using the sensor technologies in their classrooms, the framework struggled to support teachers to think beyond the sensor technology.

Since the teachers struggle to define computational thinking, their students are not likely to realize that they are engaging in the process. In conjunction with this, Carolyn has pushed the group to think about how to meaningfully articulate to students that they are engaging in computational thinking to observe mediating process MP2[6] .

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[5] Teachers articulate where CT is occurring in the storylines through highlighting specific CT practices.

[6] Students use computational thinking to help them answer their scientific questions.

One goal of curriculum aligned with the Next Generation Science Standards is to have students understand why they undertake certain activities in the classroom [125]. This includes students articulating the rationale for using the sensor technology in their investigations and describing how using the sensor technology helps them answer their science questions (MP3 and MP4). One anticipated outcome of observing MP3 and MP4 is that students see the sensor technologies as tools for science.

However, observing MP4[7] required significant input from the teachers. The students had limited to no interaction with the sensor technology before the storyline, and most did not know such tools existed, let alone how to use them. Even in Trent's classroom during Design Cycle Two, when short activities previously introduced the micro:bit, students did not readily see the micro:bit's applicability to the maglev train storyline.

Additionally, while most students wanted to use the sensor technology again, they struggled to explain how they would go about using the sensors in future investigations showing a lack of engagement in MP3[8] . Teachers did not think their students would be able to engage in further activities with the sensors without heavily scaffolded instruction driven mostly by them or step by step instructions.

The lessons learned can be grouped into lessons learned about teachers and lessons learned about students. First, teachers lack an adequate understanding of computational thinking as a distinct problem-solving resource and associate computational thinking with sensor technology usage. The utilization of the CT Practices [159] as a definition for computational thinking compounds this problem due to its tool focused design. Second, the students cannot explain why the sensor technology is an instrumental part of their scientific toolkit. This impedes their ability to understand why they are using the sensor technology and prevents them from seeing the sensor technology as tools for scientific inquiry.

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[7] Students describe why they want to use the sensor technologies in the investigation.
[8] Students articulate how they would use the sensor technologies to answer their scientific questions.

Research Questions 2: *How does what is learned influence changes to the third design cycle?* To address the lessons learned from the first two design cycles, I constructed a modified conjecture map, see Figure 4.2.

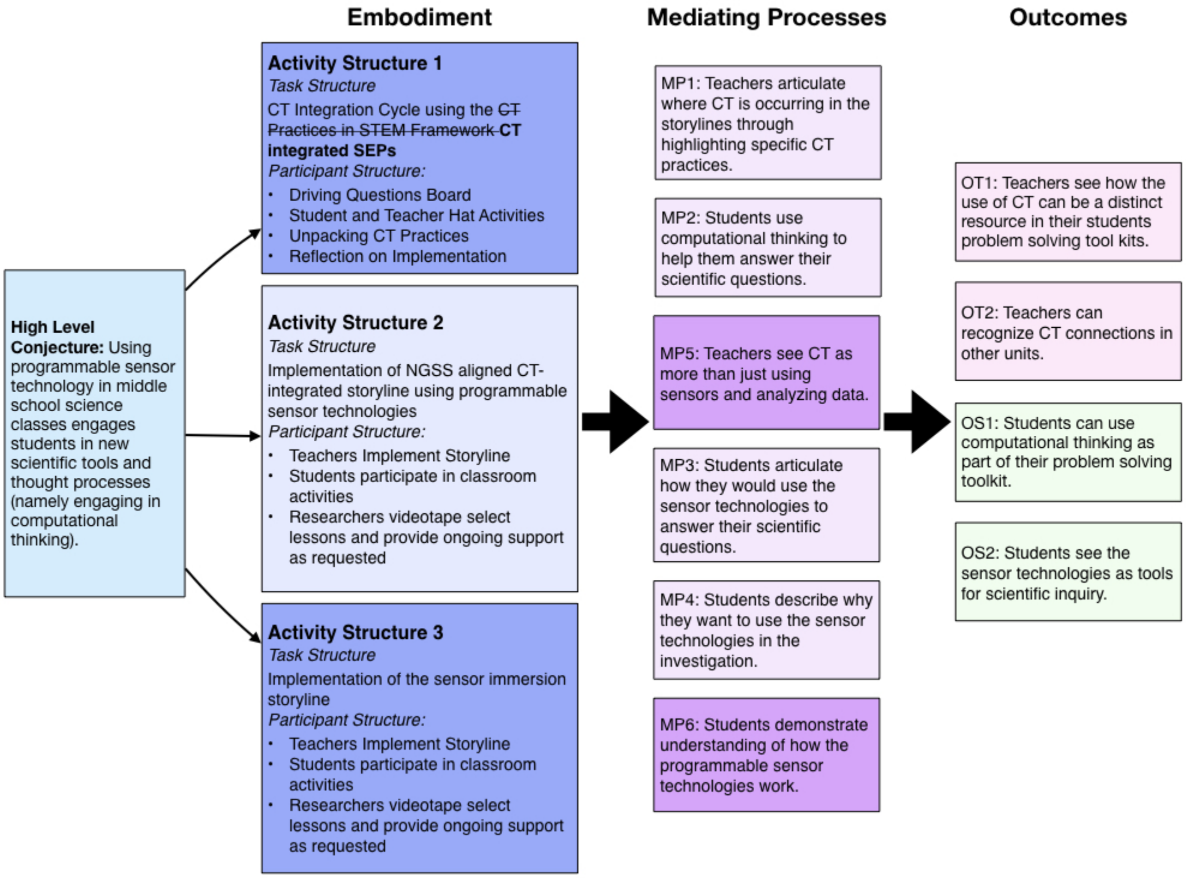


Figure 4.2: Conjecture Map updated based on lessons learned from the first two Design Cycles focusing on the programmable sensor technology and computational thinking. The darker boxes illustrate changes from the initial conjecture map.

To aid in teachers' understanding of computational thinking, I am developing an alternative understanding of computational thinking related directly to the science and engineering practices (SEPs). Since the storylines utilize the SEPs throughout, tying computational thinking to the SEPs allows for more in-depth integration throughout the storyline. This is a modification made to Activity Structure One in Figure 4.2 and the new mediating process, MP5, where teachers express understanding of computational thinking beyond the use of sensor technology and data analysis. The goal of this modification is to start with concepts teachers are familiar with, SEPs, and illustrate how they can be augmented using computational thinking.

To address the lack of sound reasoning for using the sensor technology, teachers want students to gain experience using the sensor technology and develop an understanding of its capabilities before implementing subsequent units that utilize the programmable sensor technology. The teachers and researches co-created an additional activity structure (see Figure 4.2) referred to as the sensor immersion storyline, where students investigated classroom data displays built using the sensor technology. The goal of the sensor immersion is not to have them simply go through a set of exercises using the sensor technology, but to embark on an investigation of the pipeline of the sensor technology from data collection to data analysis to data display. This activity structure supports a new mediating process, MP6, where students demonstrate an understanding of how the programmable sensor technologies work by creating models of classroom data displays.

The modified conjecture map in Figure 4.2 represents how I understand the changes made to the third design cycle. While the first two design cycles followed relatively similar paths, the third design cycle saw some significant changes instituted in the project to better support the desired outcomes. Chapter 5 describes the design and implementation of the first iteration of the sensor immersion storyline (the additional Activity Structure proposed) and discusses students understanding of how the sensor technologies work. Chapter 6 focuses on the rationale presented here for creating the expanded science and engineering practices that explicitly integrate computational thinking and presents three of the eight SEPs in their new form.

Chapter 5

Sensor Immersion

This chapter describes the creation of the sensor immersion unit during the summer of the third design cycle and its implementation during the 2019/2020 school year. It is a week-long unit that introduces students to the programmable sensor technology. The students spend the week figuring out how a classroom data display showing environmental conditions works by investigating how sensor technology can collect and display information. To do this, students build their own mini data displays to communicate information about the classroom environment.

The sensor immersion storyline augments additional storyline implementations. The goal is for students to understand how the programmable sensor technologies work and see it as an instrumental part of the scientific toolkit. Students recognize when it is appropriate to use the programmable sensor technology in their scientific investigations. The sensor immersion storyline gives students the experience they need to use the programmable sensor technologies without requiring direct instruction on how to use them during their scientific investigations. To succeed in these goals, students must develop an understanding of how the programmable sensor technologies work from their participation in the sensor immersion storyline. This chapter addresses the following two research questions.

RQ1) To what extent can participating in the sensor immersion storyline help build understanding around how the programmable sensor technology works?

RQ2) What aspects of the programmable sensor technologies did the students struggle to understand?

Several assessments could help answer the research questions such as an end of unit test, a pre/post-test, or examining student's programs for computational constructs. All of these assessments are popular ways to assess students' computational knowledge [18, 168, 70, 161]. However, the main focus was not on understanding how students' programming ability improved but rather on their overall understanding of how the programmable sensor technologies worked together. To better understand this, the analysis draws on the idea from science education to utilize student models as assessments [111, 135]. To support this activity in the curriculum, students created models of classroom data displays built using the programmable sensor technology. These models give insight into how students understand how the different pieces of the data displays fit together to create the final displays.

This chapter describes the Sensor Immersion Storyline and the analysis of the student models, followed by a description of the results. The chapter concludes with a discussion around the major themes that emerged from the model analysis and how they relate to the research questions.

5.1 Sensor Immersion Storyline

This section describes the updated programmable sensor technology, the sensor immersion storyline's design, and the final version of the sensor immersion unit that teachers implemented during the Fall of 2019. The third design cycle had ten teacher participants: four teachers returning from the previous two design cycles, and six that were new to the project. The three science teachers from design cycle two returned along with one science teacher from design cycle one who had a different role in the district during design cycle two. Of the six new teachers, three were science teachers, and three were STEM teachers.

5.1.1 Programmable Sensor Technology

The micro:bit comes with four onboard sensors: light, temperature, magnetometer, and accelerometer. However, the onboard temperature sensor is computing the temperature of the micro:bit itself. The light sensor is not an independent sensor but uses the LEDs on the micro:bit

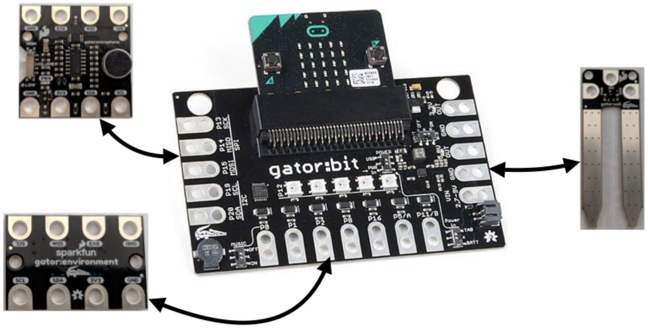


Figure 5.1: New programmable sensor technology for the third design cycle which features the micro:bit, gator:bit, and alligator clippable sensors. The sound sensor is in the top left, the environmental sensor is in the bottom left, and the soil moisture sensor on the right.

to estimate the ambient light. While the magnetometer supported the storyline during the second design cycle, additional sensors are necessary to allow for more integration throughout the other units co-designed in the project and the rest of their science curriculum. Our partners at SparkFun Technology developed a gator: bit, which makes the pins on the micro: bit, including the I2C bus, easily accessible. The gator:bit has a built-in speaker and NeoPixel array to support simple data displays, see Figure 5.1. The gator:bit is not a microcontroller itself and requires a micro:bit to work. SparkFun also developed a set of alligator clippable sensors that can be attached to the gator:bit including the environmental sensor from design cycle one (measures temperature, humidity, carbon dioxide, and total volatile organic compounds), a sound sensor, a soil moisture sensor, a UV sensor, a light sensor, and a particle sensor. All of the sensors except the soil moisture sensor and the light sensor are I2C sensors and can be daisy-chained together, which enables the usage of multiple sensors at one time, see Figure 5.1. A real-time clock and SD card data logger enable long term data logging.

To control the sensors, the micro:bit is programmed using MakeCode with the addition of custom blocks to program the different sensors, see Figure 5.2. The addition of these blocks allows for teachers and students who have become familiar with MakeCode to continue to use the same programming environment. Since these blocks are available to add to any MakeCode project, no special software or local version of MakeCode needs to be installed, which significantly increases

```
on start
    initialize gator:Environment sensors

forever
    show number get degreesF ▾ value
    pause (ms) 100 ▾
    show number Get moisture on pin P2 ▾ in Moisture ▾ using power pin P2 ▾
```

Figure 5.2: MakeCode, the programming interface used to program the micro:bit. The sensor specific blocks are added to the block menu and the program displayed shows the value from the temperature and soil moisture sensors.

usability. With the addition of these new sensors, it became even more necessary to create a sensor immersion experience to help students build capacity around these new tools.

5.1.2 Design of the Sensor Immersion Storyline

The sensor immersion storyline was co-designed with the teachers during the Summer of 2019. The summer design workshop consisted of two parts for the third design cycle. The first two days took place in June 2019, and the second two days took place in August 2019. During the first part of the summer design workshop, teachers co-designed the initial sensor immersion storyline. The storyline includes five lessons designed to take place over five class periods.

The first part of the design was settling on an anchoring phenomenon to guide the storyline. For the initial storyline, the anchoring phenomenon was a solar water heater. A series of photographs of different solar water heaters introduced the phenomenon. The functionality of the new sensors described above helped determine this new phenomenon. In particular, there are connections to the environmental sensor, light sensor, and UV sensor. This phenomenon's goal was to generate a set of questions that would lead students to explore how the utilization of different sensors could help to understand how solar water heaters worked. The remaining days focused on understanding how the sensors collect and display data and how they could be used to monitor the solar water heater. Lastly, teachers conduct a discussion about other ways that students could use the sensors in their scientific investigations.

The goal of the phenomenon was to have students generate a set of questions about the sensors. However, during the first part of the summer design workshop, when the teachers participated in the anchoring phenomenon routine, the questions they generated were mostly about how solar water heaters worked and did not bring up the sensors. Thus, even though the sensors provide opportunities to build an understanding of how the solar water heaters worked, it appeared that getting students to investigate how the sensors worked and what kinds of questions they could answer would require significant teacher direction. These observations were echoed by the participating teachers who shared that the storyline beginning with solar water heaters did not promote coherence. They suggested focusing on questions such as *How can we use sensors to measure things?* and *What do you know about sensors and how they are used?*. These are tool focused questions and do not necessarily address how the sensors are an instrumental tool in scientific inquiry. To connect the tool focused questions to science, examples of sensors in the real world anchor the storyline giving students exposure to the sensors, so they know more about them, see them as a tool to answer questions, and understand when and why to use them.

The failure of the solar water heater phenomenon to generate questions about the sensors led to the exploration of new options more closely tied to the programmable sensor technology for anchoring the sensor immersion storyline. Part of the project's original vision was to have students create physical data displays using the data collected from the sensors. Using a physical display built using the technology could generate questions tied more specifically to the programmable sensor technology. A video of wind chimes in San Francisco that generate sounds based on the amount of air pollution present [20] grounds this in the bigger picture. This video gives context to the use of sensors in the environment outside of the classroom context.

There are two classroom displays for each class to complement the video of wind chimes: one that displayed different environmental conditions in the classroom and one that monitored the soil moisture in a plant, see Figure 5.3. These displays were built using the same tools available to the students and designed specifically not to hide the technology leaving the wires, sensors, and micro:bit/gator:bit clearly visible to the students. While the remaining portion of the storyline remained more or less intact, this new anchoring phenomenon of sensors helping to understand the world replaces the solar water heaters. The final version is depicted in Figure 5.4.

For the environmental data display, the program on the micro:bit communicates information about four environmental conditions (temperature, humidity, carbon dioxide level, and noise level) using a strip of 30 LEDs and the 25 LEDs on the micro:bit. The LEDs on the micro:bit display the variable shown using a letter (e.g., T for temperature) followed by the actual value recorded by the sensor. Each environmental condition has a color associated with it (e.g., blue for humidity). The strip of 30 LEDs lights up in that color with the more LEDs lit as the value of the environmental condition increases. The LED strip blinks when a certain threshold is reached, such as when the classroom noise reaches a certain level.

The plant data display used the 5 LEDs on the gator:bit to indicate the moisture level in the plant with 5 LEDs meaning that soil was very moist and one LED, meaning that the soil was dry. When only one LED lit up, the speaker on the gator:bit played a “sad” noise.

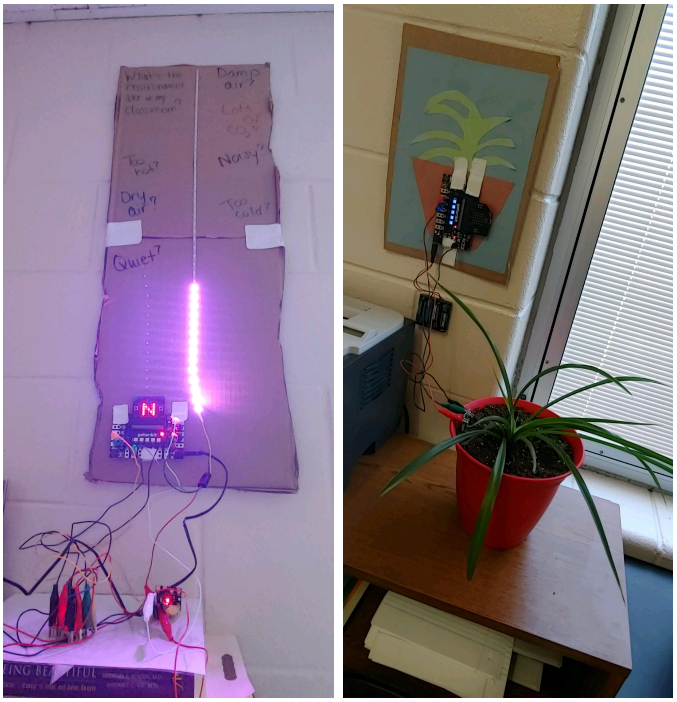
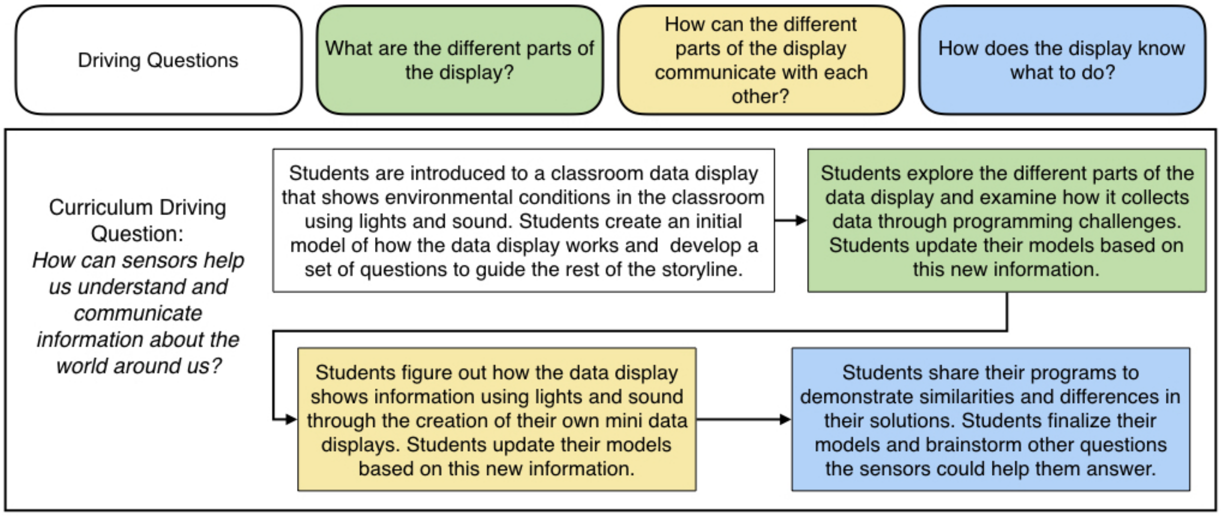


Figure 5.3: The two classroom data displays. The display on the left represents the environment in the classroom using the environmental and sound sensors. The display on the right represents the moisture level in the spider plant.

During the second part of the summer design workshop, teachers participated in the new anchoring phenomenon routine centered around the classroom data displays. This process generated a set of questions more closely matched to the capabilities of the sensors and using sensors to understand the environment. The teachers categorized the questions into three groups: 1) **basic functionality** with questions such as *What are all the different pieces?*, 2) **communication** with questions such as *What are the wires for?* and *How do the lights know the soil moisture in the plant?*, and 3) **control** with questions such as *How can I control the lights?* and *Why do the lights*



Students are introduced to a classroom data display that shows environmental conditions in the classroom using lights and sound. Students create an initial model of how the data display works and develop a set of questions to guide the rest of the storyline.

Students explore the different parts of the data display and examine how it collects data through programming challenges. Students update their models based on this new information.

Students figure out how the data display shows information using lights and sound through the creation of their own mini data displays. Students update their models based on this new information.

Students share their programs to demonstrate similarities and differences in their solutions. Students finalize their models and brainstorm other questions the sensors could help them answer.

Figure 5.4: A summary of the sensor immersion storyline

change colors?.

In addition to the change in the anchoring phenomenon, the unit includes an incremental model tracker where students create an initial model of the classroom data display and update it throughout the week as they gathered additional information. The models have three pieces: components, interactions, and mechanisms [148]. Components are the different pieces of the sensor system, interactions are how the different components work with one another, and mechanisms describe the control of the interactions. The incremental model tracker serves as a way for students to build their knowledge [135, 84] and as an assessment of students' understanding [111]. The teachers found this incremental model building practice useful in the maglev train unit. Students choose between modeling the plant with the soil moisture sensor, the classroom environmental data display, or a more general description of the programmable sensor technology collecting and displaying information. The goal of having the students build a model of the classroom data display is to help them internalize the functionality of how the different pieces of the system work together.

While typical storylines begin with a scientific phenomenon and students then work towards answering the questions they have about the phenomena [133, 122, 141], the sensor immersion storyline represents a process where students are working backward from a completed data display to figure out how it works. This process is a modification to the storyline design that explores if it would help students deeply engage with and generate questions about the programmable sensor technology in a locally relevant way. While this deviates from the specific vision of what storylines look like in the Next Generation Science Standards [87, 122, 141], it does support place-based inquiry around the use of programmable sensor technology to communicate information about the world. This criterion is critical for the SchoolWide Labs project.

5.1.3 Summary of the Sensor Immersion Storyline

The five days of the sensor immersion storyline involve the students trying to figure out how the classroom data displays work. Each day begins with its own question and builds off the previous day, culminating in a discussion about how the sensors could be useful in other scientific investigations. The sequence is outline in Figure 5.4.

Day 1: How can sensors and data displays help us understand our environment through different ways of displaying information? Ideally, the classroom data displays would have been running since the start of school in each teacher's classroom. Students do not yet know what exactly is going on with these displays in their classrooms. Students view the video where windchimes represent the amount of air pollution and explore the classroom data displays. To explore the display, students can interact with the sensors to cause changes in the display. For example, removing the soil moisture sensor from the plant causes the gator:bit to play a "sad" noise and the data display to show a decrease in moisture by displaying only one light. The students then develop a set of questions about the classroom data display and determine which group of questions to answer first. The goal is for the students first to figure out the parts of the display. The teacher can guide them in this direction if necessary.

Day 2: What are the parts of the sensor system and how can we use the sensor system to collect data? The teacher explains the different parts of the classroom data display to the students focusing on the micro:bit, gator:bit, and sensors. The students then complete a set of tutorials around data collection to help them figure out how the classroom data display gets its information, how the different pieces of the display communicate with one another, and how the students can interact with the classroom data display to alter the display. Since there are three sensors in the classroom data displays, each group picks one sensor to investigate.

Day 3: How can we use the sensor system to display information using more than numbers? Since the students learned how to collect data using the sensors during the previous day, students expressed that they wanted to explore how to display that information using more than just numbers. This process introduces students to conditional logic, so they can ask questions about the data as it is collected. Students program the micro:bit to create their own miniature data displays using the sensor they are investigating.

Day 4: How are the sensors and data displays similar and different? How can the sensor system help us in our scientific investigations? Students share their findings of the different physical quantities each sensor can measure and share the programs they created with the entire class. The goal here is for students to recognize similar patterns in all the different programs and the assembly process in order to realize that once they know how to use one sensor, they can use any sensor. Students conclude this lesson with the creation of final models of one of the classroom data displays.

Day 5: How can we use the sensor system to investigate other scientific problems? Students brainstorm other questions that the sensors might help them answer and complete an assessment task that introduces them to a new phenomenon. They describe how the sensor system could help them answer some of the questions they have about the new phenomenon.

5.2 Method of Analysis

The final models the students created represent the best insight into their understanding and struggles about how the classroom data displays work. The majority of teachers had their students create final models of the classroom data displays, but only two teachers had students update their models throughout the week. Four of the ten teachers chose to share their student models for analysis.[1] All four teachers were science teachers, and three of those were returning teachers. Table 5.1 describes the four teachers who shared their models.

The final modeling activity consists of a provided activity sheet that prompts students to draw a model of one of the classroom data displays. The activity sheet consists of a place to draw the model with one section for students to list the things they should include in their model and another section for students to write an explanation of the model. Three of the four teachers used the activity sheet while Tracy used the activity sheet for her second group of students and a blank sheet of printer paper for the first group of students.

The analysis of the student models uses an open coding approach [149] that focuses on looking for facets of student thinking [102] in the final models. This process first lists all the ideas

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[1] Sharing student artifacts is encouraged by not required by participating teachers. Three teachers completed modified versions of the sensor immersion and did not complete final models of the classroom sensor system. Three teachers chose not to share their students' work.

Table 5.1: Table outlining the teachers who selected to share their students' final models with the research team. All four are science teachers. I only counted student models that were not blank. All of Trent's and Tracy's students created a final model, 38 of Andrew's 52 students created a final model, and 31 of Mark's 86 students created a final model. FRPL stands for Free and Reduced Price Lunch which serves as a metric for the socioeconomic status of the students. Tracy saw one third of her students each trimester and thus implemented the sensor immersion storyline three times. She shared the student models from her first two implementations with me. The third implementation was interrupted due to an extended Spring Break.

Teacher	Years in Project	School FRPL	Classroom Gender	Classroom Ethnicity	Total Student Models
Andrew	2	91%	42% Female	100% non-white	38
Mark	1	95%	44% Female	92% non-white	31
Trent	3	95%	46% Female	97% non-white	98
Tracy	2	90%	39% Female	100% non-white	46

communicated by a set of student models and then categorizes them into similar groups of ideas. The goal is to figure out what ideas the students communicate and not look for the correctness of the ideas.

The analysis was a two-step process. First, the teachers worked with a small sample of student models to develop the initial set of ideas. Then, I refined those ideas using a more extensive set of student models to develop a coding guide. The coding guide considered the levels of sophistication in understanding to develop a continuum of understanding. The teachers developed the initial set of ideas because a critical component of the SchoolWide Labs project is to include practitioners in the data analysis process. Specifically, using the facets of student thinking is an instructional technique to build on students' initial knowledge around a topic [102].

At the second workshop during the third design cycle, the nine teachers present developed an initial set of categories based on six student models. The models selected illustrated the variable understanding among students of the capabilities of the sensors and data display and were from two different classrooms. Seven of the nine teachers had implemented the sensor immersion storyline before the workshop. There were two groups of teachers, and each group developed categories. Each teacher viewed each model and added sticky notes to represent the ideas they saw communicated by the student in their models of the data displays. The teachers were encouraged not to think about the correctness of the idea, just the idea itself. If they agreed with another teacher's idea, they could "+1" the idea. This activity's structure draws on a description from the STEM Teaching Tools[2] .

Group One developed five categories: Components, Interactions, Data, Display, and Coding. Components included things such as identified electronic parts. Interactions included ideas around wires connecting the parts of the system to transmit data. Data included ideas such as data can move. Display included ideas such as lights and sound. Coding included ideas around using the computer to code.

Group Two developed five categories as well: Set Up, Data, Display, Coding, and Other. Set

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[2] http://stemteachingtools.org/brief/37

Up included depictions of the sensor connected to the micro:bit using wires and general descriptions of the setup of the classroom display. Data included ideas that involved information flowing through the system (usually depicted as flowing through the wires). Display included ideas around what the classroom display was showing. Coding included ideas around using block code and the fact that the students needed to program the micro:bit. In the Other category, they included ideas that did not fit any previous categories, such as a student's analogy to the micro:bit as the brain of the system.

After developing the initial categories, I used a set of ten student models to refine the categories described above into four categories: Components, Data Flow, Display Description, and System Control. For each category, there was a 2 point scale based on understanding (0 points for no or minimal understanding, 1 point for a standard level of understanding, and 2 points for exemplary understanding). I developed an initial coding manual with descriptions of each category and level within the category. I then created groups of ten student models, including models of different levels of understanding and from different teachers in each group. In order to get interrater reliability on the coding manual, I refined the manual over four rounds of practice coding (ten models per round) with two colleagues until one colleague and I agreed on at least 80% percent of the models for each category. During each round, we refined the scale definitions within each category. A summary of the final coding manual is in Table 5.2, and Appendix B includes a complete coding manual. After successfully obtaining inter-rater reliability, I scored all the models. If there was a model that I was unsure of, I consulted my colleagues, and we came to a consensus on the score for that model.

To augment the student model scores, I conducted semi-structured teacher interviews with each of the four teacher participants after the sensor immersion unit and consulted teacher written reflections on the sensor immersion unit collected during the second professional development workshop. The semi-structured interview focused on how the implementation of the sensor immersion unit went as a whole. The teachers were also asked about each specific day of the sensor immersion unit, probing for students' understanding and struggles with how the data displays worked

Table 5.2: A summary of the categories in the coding manual.

Category	Description
Components	To receive a standard score, a student must illustrate or describe the major parts of the system: micro:bit/gator:bit, display, sensors although they do not need to draw or label the sensor explicitly. To receive an exemplary score, a student must illustrate or describe the sensor in relation to the rest of the system.
Data Flow	To receive a standard score, a student must describe data moving in the system. To receive an exemplary score, a student must describe in detail how data is moving throughout the system. Namely, they must include more information than the fact that the sensor sends information to the micro:bit.
Display	To receive a standard score, a student must describe what the data display is showing. To receive an exemplary score, a student must describe how the data display is showing that information. For example, the gator:bit makes a noise when the plant needs water.
Control	To receive a standard score, a student must explain or illustrate that programming is used to control the system. To receive an exemplary score, a student must describe how the program is controlling the system. For example, the program tells the micro:bit to ask the sensor for information.

along with students' level of engagement and interest in the investigation. Appendix A contains a complete list of the interview questions. The written reflections asked teachers: *What did you learn about teaching a unit that highlights CT?*, and *If you were to teach the sensor immersion unit again, what would you do differently?*. Lastly, I was present in each of the four teacher's classrooms for most of the lessons acting as a participant observer. This additional data gives context to the analysis of the student models and the resulting scores.

5.3 Results

There were a total of 213 models. The percentage of student models that received nonzero scores for each teacher and overall represents students who exhibited at least standard understanding. For complete results, see Table 5.3.

Table 5.3: The percentage of students from each teacher who received the following model scores.

Teacher	Model Score	Components	Data Flow	Display	Control
Andrew	0	32 (84%)	37 (97%)	38 (0%)	34 (11%)
	1	5 (13%)	1 (3%)	0 (0%)	4 (11%)
	2	1 (3%)	0 (0%)	0 (0%)	0 (0%)
Mark	0	22 (71%)	29 (94%)	25 (81%)	28 (90%)
	1	0 (0%)	2 (6%)	4 (13%)	3 (10%)
	2	9 (29%)	0 (0%)	2 (6%)	0 (0%)
Trent	0	73 (75%)	83 (85%)	78 (80%)	81 (83%)
	1	3 (3%)	12 (12%)	14 (14%)	13 (13%)
	2	22 (22%)	3 (3%)	6 (6%)	4 (4%)
Tracy	0	19 (42%)	37 (81%)	35 (76%)	39 (85%)
	1	19 (41%)	7 (15%)	9 (20%)	6 (13%)
	2	8 (17%)	2 (4%)	2 (4%)	1 (2%)
Overall	0	146 (68%)	186 (88%)	176 (82%)	182 (86%)
	1	27 (13%)	22 (10%)	27 (13%)	26 (12%)
	2	40 (19%)	5 (2%)	10 (5%)	5 (2%)

Overall the modeling activity proved very challenging for students, with most students missing critical elements of the data display system. Students were most successful at identifying the components of the classroom data display, with 32% receiving a standard or exemplary score.

Andrew had his students draw three models throughout the sensor immersion unit. Andrew's class was most successful in labeling the components and describing the control of the system with limited to no success in describing the data flow and the display. Andrew focused most of the sensor immersion storyline on programming the micro:bit and did not focus on using the sensors and the data display beyond the first and last lesson. When programming the micro:bit, the students got to choose what to program. Many chose not to use the sensors and tutorials provided in the curriculum but instead used the tutorials on the MakeCode website. In his written reflections, he wrote that his students were successful in programming the micro:bit using the MakeCode tutorials. His entire response to the question, *What did you learn about teaching a unit that highlights CT?*, revolved around students programming the micro:bit. However, he did say that when he implements the storyline again, he will spend an additional day working on the student models.

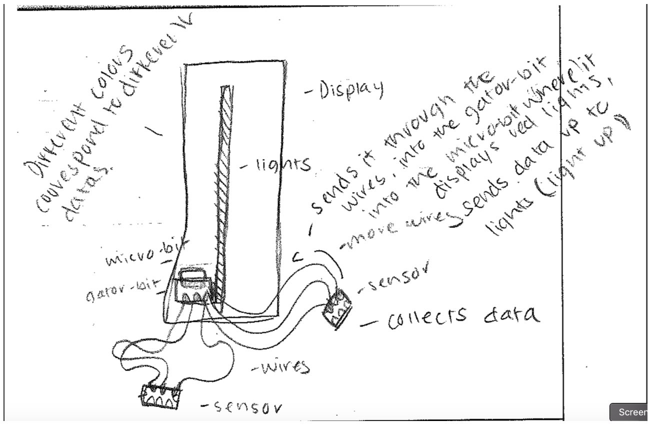
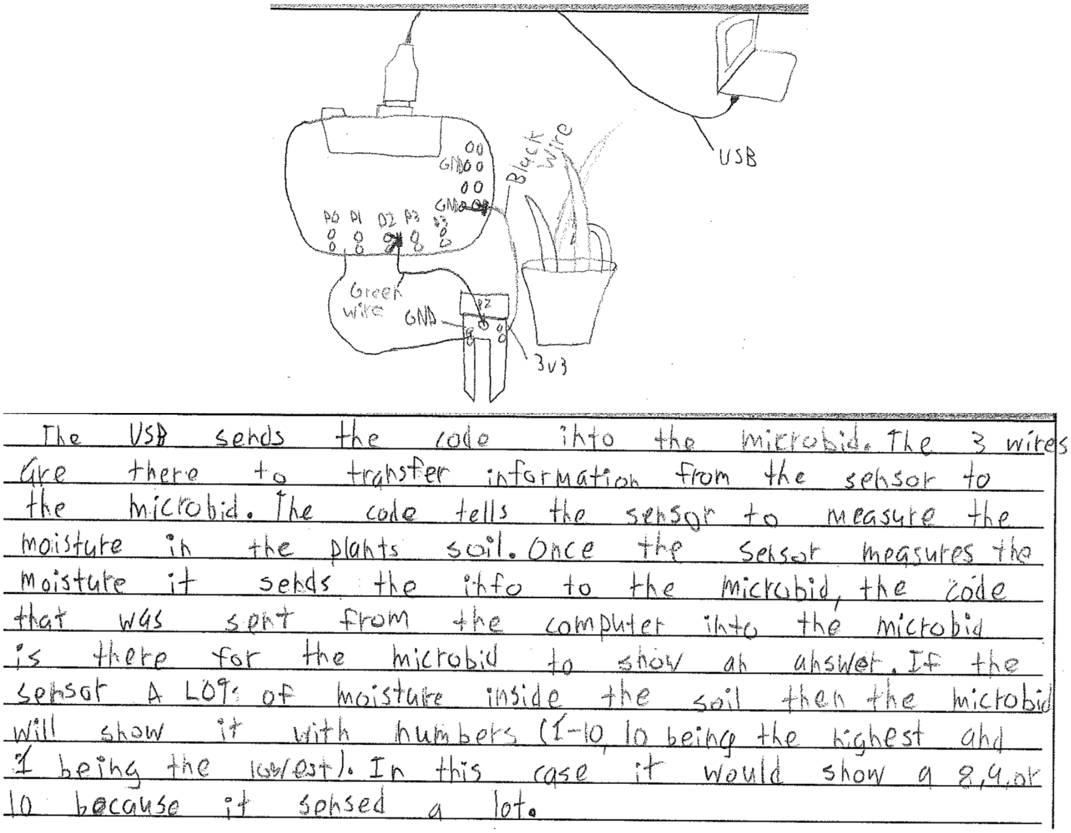


Figure 5.5: An example model from Mark's classroom. Illustrates data moving from the sensors to the micro:bit but not from the micro:bit to the sensor.

Mark was the only teacher to utilize the incremental model tracker. Mark's students performed best in the components and display categories. In particular, students who received points for components were all exemplary (2 points). When introducing the micro:bit, gator:bit, and sensors, Mark used an analogy about how the micro:bit acted like your brain, the gator:bit was like your spine, and the sensors were like you feeling things with your fingers or body. This analogy appeared to helped students differentiate the parts of the classroom data display and recognize the sensor as separate from the micro:bit and gator:bit, a common point of confusion among students.

A small group (6%) of Mark's students illustrate data flow in the model. However, no students illustrated the bi-directional data flow. The model in Figure 5.5 is an example of a student showing data moving in both directions. Mark commented that in future implementations, he would spend more time focusing on the student models and familiarizing students with how to draw good scientific models.



The USB sends the code into the microbid. The 3 wires are there to transfer information from the sensor to the microbid. The code tells the sensor to measure the moisture in the plants soil. Once the sensor measures the moisture it sends the info to the microbid, the code that was sent from the computer into the microbid is there for the microbid to show an answer. If the sensor A LOT: of moisture inside the soil then the microbid will show it with numbers (1-10, 10 being the highest and 1 being the lowest). In this case it would show a 8,9,or 10 because it sensed a lot.

Figure 5.6: An exemplary student model from Trent's classroom.

Trent had his students create an initial and a final model. Trent's students were relatively successful across all categories, with the highest percentage of nonzero scores in system control and the second highest percentage of nonzero scores in data flow and display. One of Trent's students is the only student to receive an exemplary in all four categories. This is student's model is illustrated in Figure 5.6. The explanation is the most complete explanation of how information is moving through the system. Trent is also the only teacher of the four teachers to explicitly lead a discussion around how the students completed the mini data displays for each sensor. Trent remarked that his students were very excited about collecting data with the sensors, but struggled with the analysis and display portion. This was evident in the student's discussion. They could readily see similarities and differences in the programs they wrote to collect data but were less confident discussing the data displays.

Tracy's students had the highest percentage of nonzero scores in the components, data flow, and display. Tracy utilized the classroom displays from the beginning of the school year, and students were always asking questions about them. She even used them to justify getting fans in the classroom when the first few weeks of school were hot. Of all the teachers, Tracy utilized the classroom data displays the most outside of the sensor immersion unit.

Tracy's situation is unique. She implemented the sensor immersion unit three times because her students were on a trimester schedule. The analysis includes data from her first two implementations. There were some differences in the students' models across implementations. Since she implemented the sensor immersion unit twice with two different groups of students, the analysis examines variation among her classes.

5.3.1 Tracy's Implementations

Tracy implemented the sensor immersion unit with one group of students in September of 2019 and the second group of students in November of 2019. There were 23 students in each class. Table 5.4 illustrates both groups' model scores by category.

Table 5.4: The model scores of Tracy's students broken out by the first and second implementation.

Implementation	Model Score	Components	Data Flow	Display	Control
First	0	4 (17%)	16 (70%)	20 (87%)	23 (100%)
	1	15 (65%)	7 (30%)	3 (13%)	0 (0%)
	2	4 (17%)	0 (0%)	0 (0%)	0 (0%)
Second	0	15 (65%)	21 (81%)	15 (65%)	16 (70%)
	1	4 (17%)	0 (0%)	6 (26%)	6 (26%)
	2	4 (17%)	2 (9%)	2 (9%)	1 (4%)

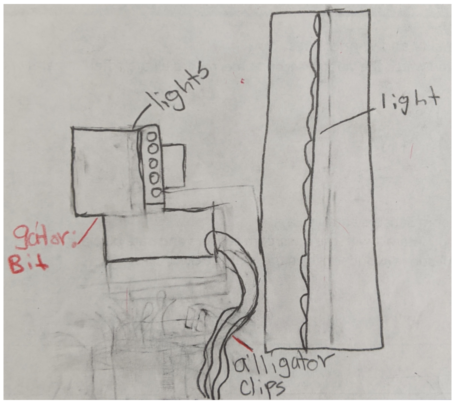


Figure 5.7: An model from Tracy's second implementation that illustrates a lack of understanding about where the sensor is located.

Tracy's first group had a larger percentage of nonzero model scores in the components and data flow categories with an exceptionally high percentage (82%) scoring in the standard (1 point) or exemplary (2 points) category on the components. Students in Tracy's second implementation struggled to differentiate between the clippable sensors and the micro:bit and gator:bit. Even students who received a one because their written explanation described the sensor did not include it in their physical drawing. Students associated the entire system with being the sensor. 8 of the 23 students received 0 for components and labels because they did not include anything connected to the alligator clips or even anything that could resemble connections at the end of the wires, see Figure 5.7 for an example of alligator clips going nowhere.

During the programming exercises, students in the second implementation would program the micro:bit and then wonder why it did not work as expected even though they never connected any sensors. Tracy's first class initially struggled with this as well, but those students tended to continue to troubleshoot the issues they were having. In contrast, many of the students in the second implementation simply gave up. Tracy hypothesized in the post-implementation interview that it was that productive struggle that allowed her students in her first implementation to succeed in differentiating the parts of the classroom data display.

During Tracy's first implementation, she had students draw their models on blank pieces of paper and did not emphasize the need to write an explanation. The explanation portion was the most common area where students received points for the display and system control categories. To better illustrate students' understanding, she used an activity sheet that explicitly asked for an explanation during the second implementation. The activity sheet is one reason students from the second implementation perform better in the display and system control categories.

Students in the second implementation performed better in the display and system control categories. However, Tracy thought her students from the first implementation would have performed even better had the activity sheets for drawing the final models been the same. The students in her first implementation were traditionally seen as less high performing than the students in her second implementation. She expressed in her written reflection that "I learned that students may need to be taught how to think through CT work. We spend so much time putting the students in a box that when we ask them to think outside the box, they have a hard time doing that. This is particularly true for the *high achieving* or *teacher pleaser* students."

A particularly compelling feature of Tracy's implementation was how upfront she is with her students around her challenges with understanding the classroom data display and using the programmable sensor technology. She discussed the struggles she has experienced during her two years participating in the project and how she relies on asking other teachers and researchers for help.

Tracy expressed that her first implementation expressed much more persistence around using the programmable sensor technology, whereas, in her second implementation, students were less willing to ask questions or try alternative solutions. They frequently just gave up and were off task for the remainder of the lesson or relied on other students to do the work. Tracy remarked that she thought that students in her first implementation were more used to struggling through concepts because they were traditionally lower performing than the students in her second implementation. In future implementations, Tracy stated that in the future, she would modify some of the lessons in the sensor immersion so that students could only be successful through failure.

5.4 Discussion

While the overall percentage of students who had models that were standard or exemplary in the four categories was small, there were some general themes around understanding and student struggles that emerged in the different categories. These themes will guide the revisions to the sensor immersion storyline and guide teachers who implement the unit in the future.

RQ1: To what extent can participating in the sensor immersion experience help build understanding around how the programmable sensor technology works?

The students showed some success in describing the components of the classroom data displays, with almost one-third of them successfully creating models that were standard or exemplary. Most students included the components in the illustrations of the models, but some students included them in the explanations. I expected students to perform best in the Components category because they can physically see the different components, and most had experience putting together the different pieces when making their own mini data displays.

If students described data moving within the classroom data display, they connected the idea that the sensor was getting the data values and sending that data to the micro:bit. To alter the value read by the sensor, students understood that they had to change the environment around the sensor (e.g., blowing on the sensors or clapping right next to the sensor). This is important for setting up future scientific investigations because students need to place the sensor in the correct location for accurate data collection.

Almost 20% of students were able to provide a general description of what the classroom data display was showing (e.g., the display indicated the plant needed to be watered or showed the temperature in the room). This shows that students understood the primary purpose of the classroom data displays.

14% of students described that programming or coding was necessary to make the classroom data display work. They connected programming to the classroom data display even though they never observed the programs that controlled the classroom data displays. The primary interaction connecting programming to control of the display was through the construction of the mini data displays.

RQ2: What aspects of the programmable sensor technologies did the students struggle to understand? Several areas of struggles emerged from the model analysis. These struggles were common reasons students did not get into the exemplary and standard categories. Teachers implementing the unit shared the students' struggles around data flow and system control.

In the Components category, students struggled to understand which part of the system was the sensor and which part is the micro:bit/gator:bit. The languaged teachers used to describe the classroom data displays illustrated this misunderstanding. They would refer to the micro:bit, gator:bit, and sensors generically as sensors.

The concept of data flowing in both directions: from the micro:bit to the sensor and the sensor to the micro:bit eluded all but 2% of students. Students who discussed data flow mentioned data going from the sensor to the micro:bit. However, the sensors have no notion of how to send data to the micro:bit unless the micro:bit asks for the sensor for that information. Students thought the sensors could control themselves. Many teachers also experience this struggle.

18% of students could describe the classroom data displays, but only 5% of students could provide details connecting the values from the sensors to changes in the classroom data displays. Without understanding how the classroom data displays showed the information from the sensors, it is difficult to see how students could use the data displays as tools to communicate information from the sensors.

Students struggled with the details around the programming, with only 2% of students providing details about how programming the micro:bit controlled the classroom data display. Students knew they had to program the sensor for it to work, but they struggled to describe how to program the micro:bit. This struggle would make it challenging to use the sensors in future scientific investigations without significant support from their teacher or tutorials.

There was some variation across teachers in how their students performed with Tracy's student performing the best overall in terms of the percentage of students receiving nonzero scores.

While all teachers had the same curriculum, each provided their own style to the implementation. Tracy initially had been unsure about using programmable sensor technology in her classroom; however, she embraced the challenge and was very excited to have the technology in her classroom. She set up the classroom data displays as soon as she got them and even used the temperature sensor to support her request for fans in the classroom during the beginning of the school year. Tracy told her students how she was involved in the SchoolWide Labs project and how it was a privilege to bring this new technology into the classroom. She gave her students extra time to create their own mini data displays. This differentiated her from Trent and Mark, who followed the curriculum more closely and did not provide extra time for their students to elaborate on the mini data displays. Andrew did not focus as much on the classroom data displays and instead spent most of the time introducing his students to programming. Differences in the uptake of the curriculum can influence student performance [13].

5.5 Conclusion

The sensor immersion unit is a very short unit with much material to cover. Teachers often focused more on having their students use the programmable sensor technology than on digging deep into the students' questions around how it worked. This was due in part to the lack of instructional time and due to teachers' lack of knowledge about how the classroom data displays worked. Teachers also missed highlighting some of the key concepts represented in the student models, such as data flow. One suggested revision to address this issue is to have the teachers construct their own data displays to anchor the unit.

However, the implementation of the sensor immersion unit was not without its successes. Students could easily explore the classroom data displays that anchored the unit. Students were able to generate many questions about the classroom data displays with all the visible programmable sensor technology. Most students designed and programmed their own mini data display using data collected from one of the sensors. Lastly, while the usage of programmable sensor technology in subsequent units has yet to be examined, there is anecdotal evidence that students are recognizing and using the sensor technology as a tool for scientific inquiry. For example, one teacher has a group of students exploring how asphalt heats up under different conditions.

As the cohort expands, there are multiple teachers in the same school participating in the project. With students now having the opportunity to experience multiple sensor immersion units, vertical alignment comes to the forefront. One strategy to support this deeper understanding of the programmable sensor technologies is through explanations around classroom data displays in the *Use, Modify, Create Paradigm* [91]. Chapter 7 outlines this modification.

Chapter 6

Science and Engineering Practices Augmented with Computational Thinking

The SchoolWide Labs project aims to integrate computational thinking into required middle school science and STEM classes. The Next Generation Science Standards [87] guide the science learning. The Next Generation Science Standards are a well established and widely used set of standards for designing science curriculum. A definition of computational thinking is necessary to support its integration into science. While there are sets of computational thinking frameworks [128, 18, 159, 1], none has the consensus and widespread adoption of the Next Generation Science Standards.

When choosing a definition of computational thinking, it needs to be detailed enough for the research team to highlight computational thinking throughout the lessons, and for teachers to understand how and when their students are engaging in computational thinking. The ability to create specific enough definitions has plagued the field and generated challenges for curriculum designers and teachers [57].

The initial phases of the project included the exploration of several existing frameworks for computational thinking. Initially, the goal was to use an existing framework because the field contains a plethora of definitions [166, 128, 8, 18, 159]. Several of these frameworks are discusses at length in Chapter 2. The Computational Thinking in Math and Science Taxonomy [159] proved to be the best initial definition for integrating computational thinking into science and STEM classes. Its language aligned with the next generation science standards, and the authors collaborated with researchers, K-12 teachers, and subject-specific experts during its development. Additionally, it aligned well with the initial sensor technology that was only capable of collecting large data sets.

For the first year of the project, the framework worked well. The week-long unit saw students engage in the Data Practices [159] during the majority of the unit. The unit used the sensor technology to collect and analyze data to determine if the school had the ideal conditions to support mold growth. While the Data Practices served as a good entry point for integrating computational thinking, focusing solely on the Data Practices during the first design cycle made it difficult to address how some teachers associated computational thinking exclusively with data collection and analysis, see Chapter 4. With that in mind, the second design cycle's goal was to create a longer, more involved unit (about maglev trains, see Chapter 4) that supported more three dimensional science learning and expanded the scope of computational thinking to include the Computational Problem Solving Practices [159]. The computational problem solving practices became relevant because the sensor technology for the second design cycle was programmable.

The longer unit led to more productive science learning; however, the identification of computational thinking outside of the programmable sensor technology proved challenging. The definition of the Data Practices and Computational Problem Solving practices relies on the tools used to collect data and analyze data. Several lessons throughout the eight lesson sequence did not require students to use the sensors or analyze data collected using the sensors, making it difficult for both the researchers and teachers to describe additional lessons that integrated computational thinking. While this was a concern of the research team, they remained committed to the CT Practices and their language. The team decided to examine the implementation of the maglev train unit to see the extent of the integration of the CT Practices. During the maglev train implementation, teachers struggled to identify when students engaged in computational thinking outside of using the sensor technology or analyzing the data collected. They equated times when their students were using the programmable sensor technologies as times when students demonstrated computational thinking, see Chapter 4.

At the first workshop during design cycle three, the teachers examined the rows of the maglev train storyline. One of the tasks they undertook was to highlight where students were engaging in computational thinking in each row. Similar to the results from the end of the second design cycle, teachers highlighted rows that used the sensor technology and data collected using the sensor technology as the only relevant computational thinking. Teachers described several rows of the storyline as not containing any computational thinking.

After this experience, the research team took a step back to examine the original goal of integrating computational thinking into science using programmable sensor technology. The goal is to see computational thinking as a problem solving approach that students could engage in during scientific inquiry. Computational Thinking experiences should not be seen as one-off experiences tied to the use of specific tools, but rather as an approach that students could rely on throughout the lessons. That is not to say that computational tools should not be involved in the process, but rather that their use can be part of the problem-solving approach but should not be the entirety of it. The goal is for computational thinking to be seamlessly integrated into science, see Figure 6.1.

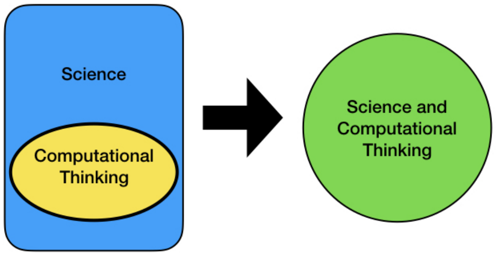


Figure 6.1: The change represented by removing the separation between computational thinking and science.

A strength of the Computational Thinking in Science and Math Taxonomy [159] was its close connection to the science and engineering practices that are already familiar to the teachers. Instead of using a different framework, the research team decided to use the science and engineering practices to understand computational thinking by explicitly calling out how computational thinking can augment each practice. While one of the eight science and engineering practices is *Using Mathematics and Computational Thinking*, the goal of the seamless integration is to demonstrate how computational thinking relates to all eight of the science and engineering practices. This chapter refers to the augmented science and engineering practices proposed as the CT-Augments

SEPs.

This chapter begins with the methodology used to create the CT-Augmented SEPs in Section 6.1. Section 6.2 describes the creation of three CT-Augmented SEPs using the process outlined in the methodology. The chapter concludes with a discussion in Section 6.3 of how researchers, curriculum designers, and teachers can use the CT-Augmented SEPs.

6.1 Methodology

Since the goal is to draw directly from the science and engineering practices [87], the process of augmenting these practices with computational thinking begins with a detailed reading and unpacking of Appendix F of the Next Generation Science Standards [147] which outlines all eight science and engineering practices.

The science and engineering practices consist of four grade bands, Grades K-2, Grades 3-5, Grades 6-8, and Grades 9-12. Each grade band has a description of what students are doing that provides evidence that students engage with the practice at the appropriate level. Bullet points describe the dimensions of practice through the students' actions, see Figure 6.2 for an example. Since SchoolWide Labs focuses on middle school students, building a CT-Augmented SEP begins by augmenting the dimensions of practice specific to middle school (grades 6-8) with computational thinking.

The first step in augmenting the science and engineering practices with computational thinking is determining what definition of computational thinking to use. The Computational Thinking in Math and Science Taxonomy [159] or one of the other frameworks described in Chapter 2.1.1 do not suffice. These frameworks help shape the definition of computational thinking as a set of practices but lack a focus on computational thinking as a problem-solving strategy supported by computational tools that help understand the world.

Three facets of computational thinking referred to as *computational approaches*, *computational processes*, and *computational tools*, influence the definitions of the CT-Augmented SEPs. *Computational approaches* are ways of thinking about solving problems or investigating phenomena (e.g., developing a system to test multiple solutions automatically, or framing a question so that computational methods and solutions can be applied). *Computational processes* are the steps taken when investigating a phenomenon or designing solutions that utilize computational skills (e.g., using computational tools, acting out a physical simulation, following the algorithmic steps in an investigation). *Computational tools* are means that students physically engage with (e.g., sensors, 3D printers, computer simulations). The definition of a generic version of a CT-Augmented SEP utilizes this understanding of computational thinking. Additionally, it describes how that generic version applies to the specific instantiation of the CT-Augmented SEP with a specific medium of integration (using a computational tool).

Each dimension of practice integrates computational thinking focusing on the *computational approaches* and *computational processes*, referred to as the CT-Augmented SEP. This intermediary step makes this document more useful to other researchers, curriculum designers, and teachers who may not be using programmable sensor technology as the medium for the integration of computational thinking. This intermediary step also allows for the recognition of computational approaches that are tool agnostic.

The third step is to describe the instantiation of each computational thinking augmented dimension of practice using the programmable sensor technologies. Here, the concretization of the CT-Augmented SEPS takes place through the use of the programmable sensor technology focusing on the *computational processes* and *computational tools*.

The specific dimensions of practice provide concrete, idealized reference examples of what students should be doing in the classroom to demonstrate their computational thinking. However, a summative overview of how *computational approaches*, *processes*, and *tools* augment each science and engineering practice provides context in which to understand the middle school specific items. These summary paragraphs highlight themes from the dimension of practice breakdown to generate a summary of the CT-Augmented SEP.

Practice 1 Asking Questions and Defining Problems

Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution. (NRC Framework 2012, p. 56)

Scientific questions arise in a variety of ways. They can be driven by curiosity about the world, inspired by the predictions of a model, theory, or findings from previous investigations, or they can be stimulated by the need to solve a problem. Scientific questions are distinguished from other types of questions in that the answers lie in explanations supported by empirical evidence, including evidence gathered by others or through investigation.

While science begins with questions, engineering begins with defining a problem to solve. However, engineering may also involve asking questions to define a problem, such as: What is the need or desire that underlies the problem? What are the criteria for a successful solution? Other questions arise when generating ideas, or testing possible solutions, such as: What are the possible trade-offs? What evidence is necessary to determine which solution is best?

Asking questions and defining problems also involves asking questions about data, claims that are made, and proposed designs. It is important to realize that asking a question also leads to involvement in another practice. A student can ask a question about data that will lead to further analysis and interpretation. Or a student might ask a question that leads to planning and design, an investigation, or the refinement of a design.

Whether engaged in science or engineering, the ability to ask good questions and clearly define problems is essential for everyone. The following progression of Practice 1 summarizes what students should be able to do by the end of each grade band. Each of the examples of asking questions below leads to students engaging in other scientific practices.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Asking questions and defining problems in K–2 builds on prior experiences and progresses to simple descriptive questions that can be tested. ● Ask questions based on observations to find more information about the natural and/or designed world(s). ● Ask and/or identify questions that can be answered by an investigation. ● Define a simple problem that can be solved through the development of a new or improved object or tool.	Asking questions and defining problems in 3–5 builds on K–2 experiences and progresses to specifying qualitative relationships. ● Ask questions about what would happen if a variable is changed. ● Identify scientific (testable) and non-scientific (non-testable) questions. ● Ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships. ● Use prior knowledge to describe problems that can be solved. ● Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost.	Asking questions and defining problems in 6–8 builds on K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models. ● Ask questions ○ that arise from careful observation of phenomena, models, or unexpected results, to clarify and/or seek additional information. ○ to identify and/or clarify evidence and/or the premise(s) of an argument. ○ to determine relationships between independent and dependent variables and relationships in models. ○ to clarify and/or refine a model, an explanation, or an engineering problem. ○ that require sufficient and appropriate empirical evidence to answer. ○ that can be investigated within the scope of the classroom, outdoor environment, and museums and ○ other public facilities with available resources and, when ○ appropriate, frame a hypothesis based on observations and scientific principles. ○ that challenge the premise(s) of an argument or the interpretation of a data set. ● Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.	Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. ● Ask questions ○ that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. ○ that arise from examining models or a theory, to clarify and/or seek additional information and relationships. ○ to determine relationships, including quantitative relationships, between independent and dependent variables. ○ to clarify and refine a model, an explanation, or an engineering problem. Evaluate a question to determine if it is testable and relevant. ○ Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory. ○ Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design. ● Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations.

Figure 6.2: The text from Appendix F for the first science and engineering practice, Asking Questions and Defining Problems. It includes a summary paragraph and grade band specific dimensions of practice (bullet points) to describe what students are doing when they engage in this practice. Image adapted from https://www.nextgenscience.org/.

6.2 Science and Engineering Practices Augmented with Computational Thinking

This section outlines three of the eight CT-Augmented Science and Engineering Practices: *Asking Questions and Defining Problems*, *Planning and Carrying Out Investigations*, and *Constructing Explanations and Designing Solutions*. These three practices represent a potential implementation sequence of the practices in the classroom. The plan is to complete all eight CT-Augmented SEPs in the future.

There is a short description of the original practice, followed by a longer description of its augmentation with computational thinking. After the introductory paragraphs, there is a description of each middle school dimension of practice for that specific practice, including the generic version and the instantiation with the programmable sensor technologies. The description of each augmented practice concludes with an example scenario of the practice in action drawn from the co-designed units and observations from teachers' implementation of these units. However, they are meant as illustrations and not as depictions of what happened in a given classroom.

6.2.1 Asking Questions and Defining Problems

Asking Questions (see Figure 6.2) arise in the science classroom from curiosity about how the world works either through the anchoring phenomenon routine or based on the results from previous investigations about the phenomenon. Students should phrase these questions so they can collect evidence through research or investigations to help them explain the question grounded in data. *Defining Problems* require students to determine the scope of the problem they want to solve and ask questions about why they would want to solve this problem. This problem relates to a phenomenon they are investigating.

When engaging in *Asking Questions* augmented with computational thinking, students utilize a *computational approach* to break down a complex question into a set of smaller questions that are easier to investigate, but can provide insight into the larger question. Other examples of *computational approaches* include students asking detailed questions instead of general questions, and students reframing questions in order to answer them using the tools at hand. Part of reframing the questions is to recognize where specific *computational tools* are appropriate to use. Reframing questions to use specific *computational tools* requires students to engage in *computational processes*. To ensure that *computational tools* can be used to answer the question, students must understand how they use the *computational tools*.

When *Defining Problems* (see Figure 6.2) is augmented with computational thinking students engage in a *computational approach* to define the problem in sufficient detail that solutions can be proposed. Part of the problem definition process is determining if *computational tools* can be used appropriately. That process entails that students use *computational processes* to define the problem so that the *computational tool* can be used to solve it.

6.2.1.1 Middle School Description

(1) Asks Questions

- CT-Augmented SEP. Ask specific questions that can be investigated using the tools at hand, *computational approach*. Reframe questions so that the optimal tools (including *computational tools*) can be used to discover answers.
- Instantiation with sensors. Ask specific questions so that the sensors present themselves as a key component of figuring out the answers. Reframe general questions so that they can tackle using the sensors. Reframe specific questions into related questions that can be answered using the sensors. All three of these involve the use of *computational processes* applied to the use of the programmable sensor technology.

(2) Define a design problem that can be solved by developing an object, tool, process, or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.

- CT-Augmented SEP. Define a design problem that can be solved using computational tools or approaches. Develop a rigorous set of design criteria and constraints, *computational approach.* Describe the limitations of the problem.

- Instantiation with sensors. Define a problem that the sensors can provide a solution for using *computational processes.* Describe why sensors are appropriate tools to solve the problem and discuss any limitations of using the sensors, *computational processes.*

6.2.1.2 Example Scenario

Students explore how a classroom vermicompost bin turns food scraps into soil that is rich in nutrients. A student raises the question, *what does a compost bin need to change food into soil?* This question, in its original form, is useful but too general to undertake specific investigations. The students brainstorm smaller, related questions that they could investigate. They conclude that the question has two components: the environmental conditions inside the compost bin and the makeup of the compost bin itself. Questions about the environmental conditions include, *What conditions in a compost bin make the best compost?* and *What conditions in a compost bin affect the speed of decomposition.* Questions about the contents of the bin include *How does the worm help turn food scraps into fertilizer?* and *How can we tell if compost is good?*

The students recognize that they could use the micro:bit, environmental sensor, and soil moisture sensor to learn about the conditions inside the compost bin. Students further refine the question *What conditions in a compost bin affect the speed of decomposition?* to *How can soil moisture, temperature, humidity, and carbon dioxide levels determine the speed of decomposition?* and a generate a subquestion *How do varying levels of soil moisture, temperature, humidity, and carbon dioxide affect the quality of the compost bin?* based on the original question *How can we tell if compost is good?*

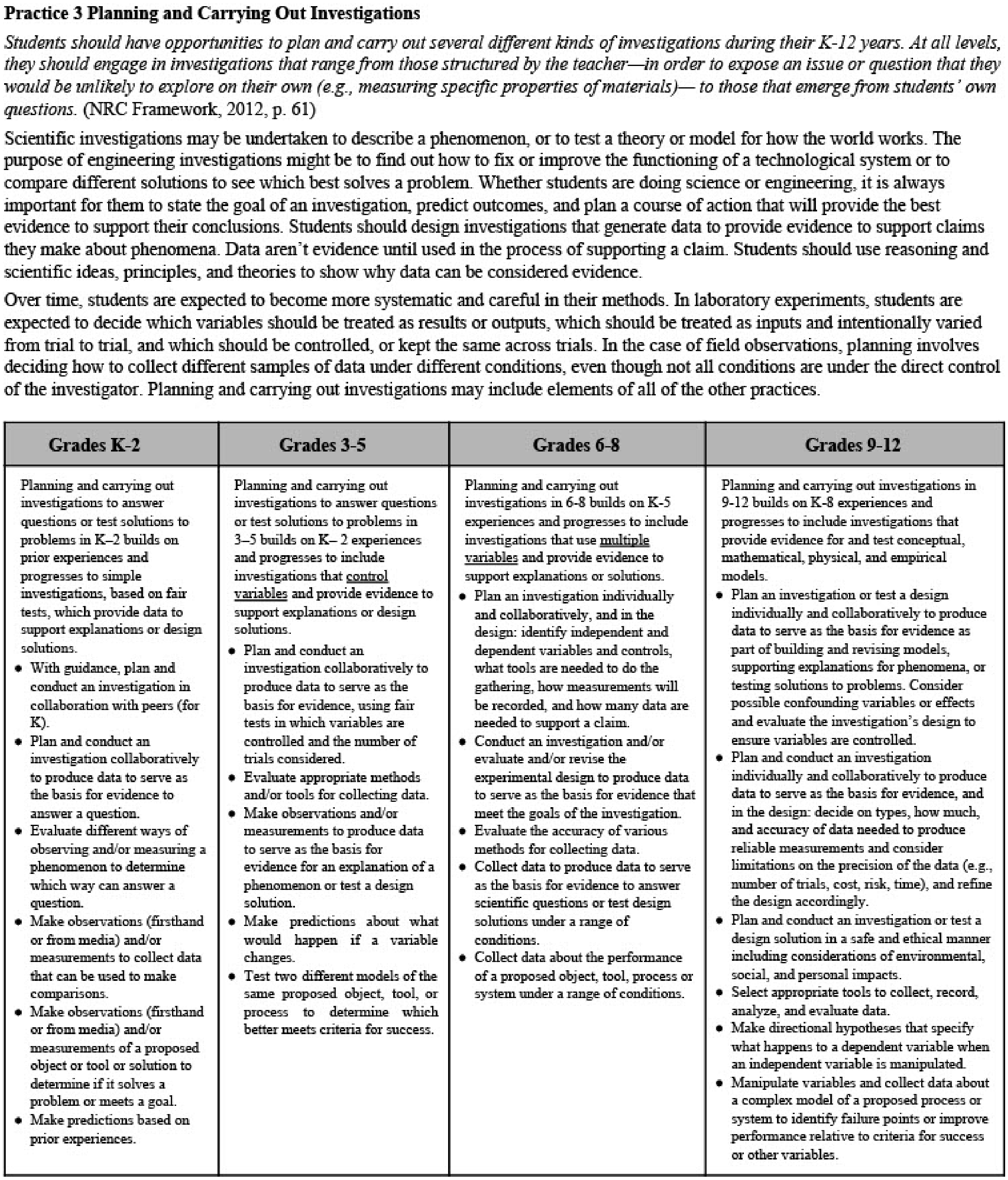
In the scenario above, students are engaging in the CT-Augmented *Asking Questions and Defining Problems* practice. First, students use *computational approaches* to refine the original question into a more detailed set of questions about the compost bin. After refinement, students explore how the tools at their disposal could help them answer their questions. Using *computational* *processes*, they further refine their questions so they can use the programmable sensor technology to collect data to help them understand the speed and quality of the compost produced.

6.2.2 Planning and Carrying Out Investigations

Planning and Carrying Out Investigations (see Figure 6.3) in the science classroom are exploratory practices where students try to figure out aspects of a phenomenon or test their ideas about the phenomenon. Students create a goal for the investigations along with their predicted outcomes and the rationale behind them. Then students develop a plan for their investigation that should include not only what the students are going to do but also how they will use the information gathered to build their understanding.

When *Planning and Carrying Out Investigations* is augmented with computational thinking, it retains the same process beginning with a goal and predicted results followed by the creation of the investigation plan. When creating the investigation plan, students strive to use a *computational approach* to describe their plan by generating a step-by-step procedure, algorithmically, with sufficient detail that it does not require inference if students were to trade their plans with one another. Other *computational approaches* revolve around the following: Students explore the different tools they have at their disposal and discuss the rationale for why the tools they choose are appropriate. They should specifically call out concepts like the accuracy of the information collected and ways to improve accuracy.

If they determine a *computational tool* would be used in the investigation, students should clearly outline the *computational processes* they undertake while using the tool (e.g., students include pseudocode in their investigation plan or specifically talk about how they will manipulate a computational simulation by discussing which variables they will manipulate and why). Additionally, they describe what *computational processes* can be used to automate parts of the investigation to allow them to spend more time on other tasks. They discuss the effect of automation on the integrity of the data. Lastly, students design *computational processes* with attention to modularity and abstraction to support reuse (e.g., recognizing the patterns in collecting data using the sensors



Practice 3 Planning and Carrying Out Investigations

Students should have opportunities to plan and carry out several different kinds of investigations during their K-12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)— to those that emerge from students' own questions. (NRC Framework, 2012, p. 61)

Scientific investigations may be undertaken to describe a phenomenon, or to test a theory or model for how the world works. The purpose of engineering investigations might be to find out how to fix or improve the functioning of a technological system or to compare different solutions to see which best solves a problem. Whether students are doing science or engineering, it is always important for them to state the goal of an investigation, predict outcomes, and plan a course of action that will provide the best evidence to support their conclusions. Students should design investigations that generate data to provide evidence to support claims they make about phenomena. Data aren't evidence until used in the process of supporting a claim. Students should use reasoning and scientific ideas, principles, and theories to show why data can be considered evidence.

Over time, students are expected to become more systematic and careful in their methods. In laboratory experiments, students are expected to decide which variables should be treated as results or outputs, which should be treated as inputs and intentionally varied from trial to trial, and which should be controlled, or kept the same across trials. In the case of field observations, planning involves deciding how to collect different samples of data under different conditions, even though not all conditions are under the direct control of the investigator. Planning and carrying out investigations may include elements of all of the other practices.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Planning and carrying out investigations to answer questions or test solutions to problems in K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions. • With guidance, plan and conduct an investigation in collaboration with peers (for K). • Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence to answer a question. • Evaluate different ways of observing and/or measuring a phenomenon to determine which way can answer a question. • Make observations (firsthand or from media) and/or measurements to collect data that can be used to make comparisons. • Make observations (firsthand or from media) and/or measurements of a proposed object or tool or solution to determine if it solves a problem or meets a goal. • Make predictions based on prior experiences.	Planning and carrying out investigations to answer questions or test solutions to problems in 3–5 builds on K– 2 experiences and progresses to include investigations that control variables and provide evidence to support explanations or design solutions. • Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered. • Evaluate appropriate methods and/or tools for collecting data. • Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution. • Make predictions about what would happen if a variable changes. • Test two different models of the same proposed object, tool, or process to determine which better meets criteria for success.	Planning and carrying out investigations in 6-8 builds on K-5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or solutions. • Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. • Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation. • Evaluate the accuracy of various methods for collecting data. • Collect data to produce data to serve as the basis for evidence to answer scientific questions or test design solutions under a range of conditions. • Collect data about the performance of a proposed object, tool, process or system under a range of conditions.	Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. • Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. • Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts. • Select appropriate tools to collect, record, analyze, and evaluate data. • Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated. • Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.

Figure 6.3: The text from Appendix F for the third science and engineering practice. It includes a summary paragraph and grade band specific dimensions of practice (bullet points) to describe what students are doing when they are engaging in this practice. Image adapted from https://www.nextgenscience.org/.

and creating a function that takes in a sensor value as a variable).

6.2.2.1 Middle School Description

(1) Plan an investigation individually and collaboratively. In the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data points are needed to support a claim.

- CT-Augmented SEP. During the planning of an investigation determine the appropriate tools from the available options, including if and when *computational tools* might be appropriate (*computational approach*), and how to utilize these tools (*computational process*) to collect the necessary types and amount of data to use as evidence to support a claim.
- Instantiation with sensors: Describe why sensors are an appropriate *computational tool* to use in their investigations through an explanation of how automated data collection is appropriate, and a statement of the accuracy and ease of use of sensors. Determine which sensors to use based the data needed for the investigation by identifying: what the sensors can measure and what the investigation needs to measure. If a specific sensor does not exist, explain how measurements taken using the available sensors would help answer questions about the phenomenon under investigation (i.e., proxy variables such as changes in temperature represent a chemical reaction).

(2) Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as evidence that meets the goals of the investigation.

- CT-Augmented SEP. Evaluate experimental designs for accuracy and potential areas of confusion. Revise experimental designs to include all the details, so someone else could copy the experiment (*computational approach*). Examine alternative methods of data collection (*computational process*).

- Instantiation with sensors. Determine if the steps for using the sensors in the investigation provide sufficient instructions for how to program the micro:bit. Determine if using the sensors will provide evidence that meets the goals of the investigation. Revise the investigation plan based on the above two points.

(3) Evaluate the accuracy of various methods for collecting data.

- CT-Augmented SEP. Explore ways to automate the testing accuracy of methods for collecting data (*computational process*). Explain why certain methods are more accurate than others (*computational approach*).
- Instantiation with sensors. Create programs to evaluate the accuracy of different sensors, (*computational process*). Determine how the creation of the programs affects the accuracy of data collection (e.g., how often data is collected, what triggers the sensor to take a reading), (*computational process*). Compare the sensors to other tools for collecting data and describe which one is most accurate and why, (*computational process*).

(4) Collect data to produce data to serve as the basis for evidence to answer scientific questions or test design solutions under a range of conditions.

- CT-Augmented SEP. Implement and ensure that the data collection procedures are written in enough detail to avoid inference and are appropriate and accurate to answer the scientific question (*computational approaches*).
- Instantiation with sensors. Program the micro:bit (*computational process*) to collect data. Debug the program (*computational process*) to ensure accuracy of data collection.

(5) Collect data about the performance of a proposed object, tool, process, or system under a range of conditions.

- CT-Augmented SEP: Explore the most effective ways to test a system under a range of conditions, including potentially automating the process to test more conditions, *computational approach.*
- Instantiation with sensors. Program the micro:bit (*computational process*) to collect data about the proposed object, tool, process, or system under a range of conditions. Test the sensors under a range of conditions, (*computational process*).

6.2.2.2 Example Scenario

Students want to investigate their school for the conditions for mold growth. The investigation will help them understand how mold gets resources to grow from the environment. Students choose a location in their school to explore and create a hypothesis about whether or not the conditions for mold growth exist. For example, one group of students choose to look at the gym locker room because it is usually warm and wet, the optimal conditions for mold growth. The students want to know just how warm and how wet the locker room is. They know they could use a thermometer to measure how warm it is, but they are not sure how to measure how wet the locker room is. Another piece of information they learned earlier in the week is that mold needs time to grow. The students do not think measuring the temperature just once will give them enough information. Also, they do not want to stay at school in the evening or on the weekend to collect data. Ideally, they would like a tool that can independently collect temperature and moisture information over a period of time. This seems like the perfect opportunity to use the programmable sensor technology to automate the process. The students create a detailed plan for how they will carry out the investigation, including information on the amount of time to collect data, the amount of data to collect, and pseudocode for how they will program the micro:bit. The plan also explores how they will analyze their data using a time-series graph and eliminate outliers based on distance from the average (i.e., remove erroneous data points such as extreme temperature readings). After each group of students has created their plan for investigation, the teacher randomly assigns the group a different plan to carry out in order to determine if the instructions were specific enough.

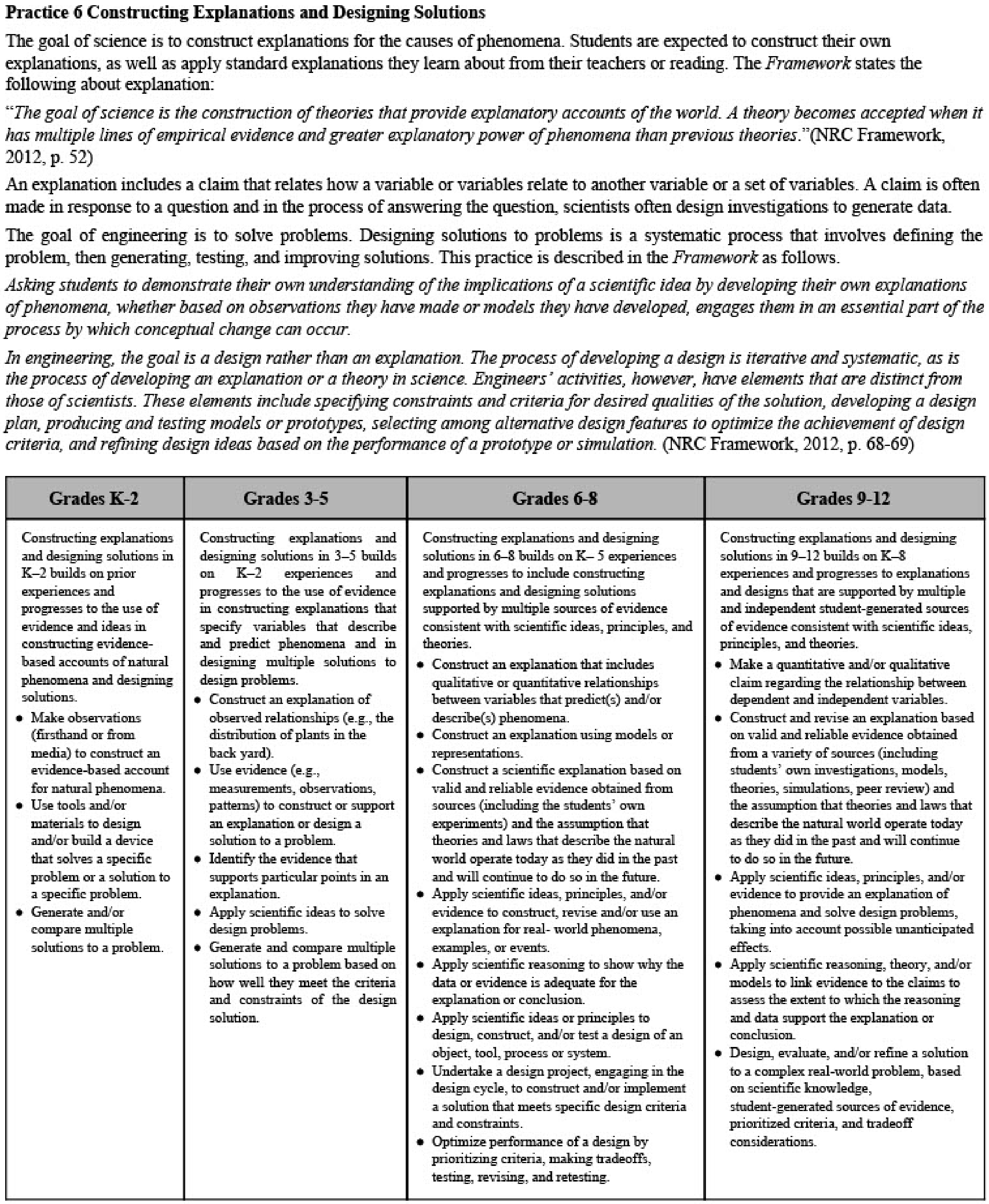
Here, students are engaging in the first two CT-Augmented dimensions of practice for *Planning and Carrying Out Investigations* described above. Students determine that they want to use the programmable sensor technology because it allows them to automate data collection over a long period of time, demonstrating the use of *computational processes* and *computational tools*. During the planning phase, the students need to provide enough details through a *computational approach* so that another group of students can conduct the investigation they designed. Lastly, they use a *computational approach* to revise other students' investigation plans to ensure that input from the students who originally designed them is unnecessary.

6.2.3 Constructing Explanations and Designing Solutions

Constructing Explanations (see Figure 6.4 in science classrooms involves students providing reasoning for the causes and effects of a scientific phenomenon. Often these explanations include results from the investigations the students carried out earlier. *Designing Solutions* revolves around students creating solutions to a problem related to the phenomenon under investigation. The solution is designed in a systematic fashion adhering to a set of design constraints.

When *Constructing Explanations* is augmented with computational thinking, the explanations include a rationale for why the data they collect is appropriate to support their explanation. Explanations include a systematic discussion of how the different pieces of data relate to one another and how each piece of information contributes to the explanation. Students utilize *computational approaches* to explore similar explanations from past experiments to look for patterns in their explanations to generate a more general explanation for a set of phenomena or use rationale from a previous explanation to support their current explanation.

When *Designing Solutions*, students take into account how *computational tools* and their corresponding *computational processes* could help or hinder their progress towards a solution. Students develop a procedure and a detailed set of design constraints before embarking on the actual design using *computational approaches*. Designing solutions should be subject to the same rigor as planning an investigation supporting anyone to recreate their process. Additionally, if students



Practice 6 Constructing Explanations and Designing Solutions

The goal of science is to construct explanations for the causes of phenomena. Students are expected to construct their own explanations, as well as apply standard explanations they learn about from their teachers or reading. The *Framework* states the following about explanation:

"*The goal of science is the construction of theories that provide explanatory accounts of the world. A theory becomes accepted when it has multiple lines of empirical evidence and greater explanatory power of phenomena than previous theories.*"(NRC Framework, 2012, p. 52)

An explanation includes a claim that relates how a variable or variables relate to another variable or a set of variables. A claim is often made in response to a question and in the process of answering the question, scientists often design investigations to generate data.

The goal of engineering is to solve problems. Designing solutions to problems is a systematic process that involves defining the problem, then generating, testing, and improving solutions. This practice is described in the *Framework* as follows.

Asking students to demonstrate their own understanding of the implications of a scientific idea by developing their own explanations of phenomena, whether based on observations they have made or models they have developed, engages them in an essential part of the process by which conceptual change can occur.

In engineering, the goal is a design rather than an explanation. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation. (NRC Framework, 2012, p. 68-69)

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Constructing explanations and designing solutions in K–2 builds on prior experiences and progresses to the use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions. • Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena. • Use tools and/or materials to design and/or build a device that solves a specific problem or a solution to a specific problem. • Generate and/or compare multiple solutions to a problem.	Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems. • Construct an explanation of observed relationships (e.g., the distribution of plants in the back yard). • Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem. • Identify the evidence that supports particular points in an explanation. • Apply scientific ideas to solve design problems. • Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.	Constructing explanations and designing solutions in 6–8 builds on K– 5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. • Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena. • Construct an explanation using models or representations. • Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real- world phenomena, examples, or events. • Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion. • Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system. • Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. • Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and retesting.	Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. • Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Figure 6.4: The text from Appendix F for the sixth science and engineering practice. It includes a summary paragraph and grade band specific dimensions of practice (bullet points) to describe what students are doing when they are engaging in this practice. Image adapted from https://www.nextgenscience.org/.

deem certain *computational tools* appropriate, they should outline the *computational processes* they will use in the solution design.

6.2.3.1 Middle School Description

(1) Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena.

  - CT-Augmented SEP. Construct an explanation using *computational approach*) that builds on the qualitative or quantitative relationships between variables observed potentially using *computational tools* to predict and/or describe phenomena. Using a *computational approach* ensures the construction of detailed, systematic explanation.
  - Instantiation with sensors. Utilize the data collected by the sensors to predict or describe information about the phenomena. Using *computational processes*, construct a data display that demonstrates relationships between variables. Construct a simulation of the phenomena using the sensors that illustrates relationships between variables (*computational processes*). One possibility uses the lights and speaker on the micro:bit/gator:bit.

(2) Construct an explanation using models or representations.

  - CT-Augmented SEP: Organize the constructed explanation using a *computational approach.* Include in the explanation of any relevant computational models, representations, or simulations.
  - Instantiation with sensors. Using *computational processes*, fabricate a data display using the programmable sensor technology as part of their explanation or create a simulation of the phenomenon under investigation using the sensors to explain what is happening.

(3) Construct a scientific explanation based on valid and reliable evidence obtained from sources

(including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

- CT-Augmented SEP. Using a *computational approach*, construct a scientific explanation based on valid and reliable evidence obtained using sources (including computational sources). The computational approach is used to provide the necessary amount of detail laid out in an organized fashion.
- Instantiation with sensors. Use information collected using the sensors in their explanations (*computational processes*. Explain why the data they collected is valid and reliable, and the strategies they utilized during the experimental design to guarantee valid and reliable data (*computational approach*. Explain the elimination of any outlying data.

(4) Apply scientific ideas, principles, and/or evidence to construct, revise, and/or use an explanation for real-world phenomena, examples, or events.

- CT-Augmented SEP. Use a *computational approach* to apply evidence by providing a step by step explanation for how the evidence explains the real-world phenomena, examples, or events
- Instantiation with sensors. Utilize data collected from the sensors in explanations. Construct a computational simulation of the phenomena using the sensors (*computational processes*).

(5) Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion

- CT-Augmented SEP. Apply scientific reasoning using a *computational approach* to show why data or evidence collected using *computational tools* and *computational processes* is adequate for the explanation or conclusion. Use a *computational approach* to apply scientific reasoning means laying out the explanation in a rigorous manner and providing all necessary details.

- Instantiation with sensors. Students explain why the sensors were an appropriate tool for data collection. Students articulate why their computational methodology for using the sensors is adequate for explaining the phenomenon. Students discuss any limitations of the sensors.

(6) Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process, or system.

- CT-Augmented SEP. Apply scientific ideas or principles along with *computational approaches* to design, construct, and/or test a design of an object, tool, process, or system. The *computational approach* requires providing systematic details and rationale.
- Instantiation with sensors. Use *computational processes* to program the sensors to design a tool to collect information related to the phenomenon. Use the sensors to construct computational simulations to test their theories about the phenomenon. (*computational processes*).

(7) Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints.

- CT-Augmented SEP. Undertake a design project that uses computational approaches, processes, and/or tools to engage in the design cycle, construct and/or implement a solution that meets specific design criteria and constraints
- Instantiation with sensors. Utilize sensors where appropriate to meet the design criteria. Discuss why sensors are appropriate to use in the given context (*computational approach*). Use *computational processes* to program sensors to explore optimal conditions for design constraints.

(8) Optimize the performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and retesting.

- CT-Augmented SEP. Use *computational approaches* to systematically prioritize criteria. Explore automated techniques to test the performance of a design to determine the optimal performance. Use *computational approaches* to design a rigorous approach to testing (e.g., organize the tests using a flow chart).
- Instantiation with sensors. All of the following illustrate *computational processes* in action. Program the sensors to develop tests for their designs. Develop simulations to explore tradeoffs in their designs. Automate the testing process of their designs. Use the sensors as part of whatever they are designing. Utilize if/then/else logic to explore tradeoffs.

6.2.3.2 Example Scenario

Students are trying to figure out how a maglev train floats. They have just finished investigating fixed magnetic fields using iron filings that display the shape of the field and the micro:bit, which gives a numerical value to the magnetic field's strength and direction. After examining the qualitative data they collected from the iron filings and the quantitative data collected using the micro:bit, students write an explanation for why the maglev train floats. Their explanation includes relationships between the qualitative and quantitative information, such as the magnetic field is stronger when the lines of the iron filings are closer together. Students also observed that magnets could attract and repel each other. When magnets are attracting, the iron filings surrounding each magnet look like they are merging, whereas when they are repelling, the iron filings surround each magnet do not touch. Using the micro:bit, students noticed that when two magnets were attracting, one magnet had a positive polarity, and the other had a negative polarity. However, when they were repelling, both magnets had either a positive or a negative value. The action of fields repelling each other seems to be a way that the maglev train could float. It would be important that the magnets do not repel too much because the train would fly off the tracks. Students hypothesize that the micro:bit could help them figure out the ideal strength of magnets to use to make something float.

In the scenario, students engage with the first and sixth dimensions of practice of the CT-Augmented *Constructing Explanations and Designing Solutions* Practice. Students describe how to use both the qualitative data from the iron filing experiment and quantitative data about the magnetic strength from the micro:bit to describe how repelling magnets could be the reason that maglev trains float. The explanation is detailed, highlighting what the students learn from both experiments and how it applies to their final solution. Reliance on the accuracy of both kinds of data represents a *computational approach.* Additionally, students engage in the sixth dimension of practice by hypothesizing that the micro:bit could help them determine the correct strength of the magnets to prevent the train from derailing, demonstrating engagement with *computational processes* and *computational tools.*

6.3 Discussion

This section discusses the potential applications for the CT-Augment Science and Engineering Practices. Having all eight science and engineering practices augmented with computational thinking would be helpful for a variety of audiences and purposes, both as part of the SchoolWide Labs project and for the field more broadly.

6.3.1 Computational Thinking Integration in SchoolWide Labs

For the SchoolWide Lab project, the CT-Augmented Science and Engineering Practices serve two main goals. First, as the definition of computational thinking integration in both the CT-Integration Cycle and the Productive Integration Toolkits. Second, as a metric for analysis for finding evidence of students engaging in computational thinking when teachers implement the units.

As the new definition of computational thinking integration, the CT-Augmented Science and Engineering Practices provide the basis for defining where and how computational thinking should occur in the co-designed storylines. This process should entail revising each storyline to highlight how computational thinking connects to the science and engineering practices already highlighted in each lesson. The existing locations of the Data Practices and Computational Problem Solving Practices represent a starting point for revising the integration. This would be followed by examining each row and its corresponding science and engineering practices to augment the row with computational thinking.

In addition to modifying the existing storylines and units, the CT-Integration cycle will introduce these new ideas. The CT-Augmented science and engineering practices can help us address some of the questions regarding computational thinking that the teachers posed throughout the design cycles (see Chapter 4) such as *How can we develop a shared vocabulary around computational thinking?*, *What does computational thinking look like in the classroom?*, and *What does computational thinking look like in our current curriculum and the storylines we are creating?*. The goal is to eventually build the CT-Augmented Science and Engineering Practices out to include all grades, just like the original science and engineering practices. This would provide information on vertical trajectories for students learning of computational thinking in science, another question raised by our teacher partners. This is an initial draft of the science and engineering practices augmented with computational thinking. As the project continues, the practices will be revised based on the experience of the researchers and the teachers' feedback as they engage with these practices in the classroom.

For the upcoming year, a research task is to examine the video collected from three iterations of the design cycle to look for teachers leading and students engaging in computational thinking. The first step to determine if and when this integration is occurring is to develop a manual that describes what computational thinking looks like in the classroom. The CT-Augmented Science and Engineering practices can serve as a basis for developing this manual. First, the updated storylines and lessons can provide a guide on what practices are relevant. Additionally, the language in the CT-Augmented Science and Engineering Practices around what students are doing in the classroom can provide an initial description of the language students should be using when engaging with computational thinking.

6.3.2 Guidelines for Implementing the CT-Augmented SEPs

The CT-Augmented Science and Engineering Practices can also be of service to other projects exploring how to integrate computational thinking in science. This section describes how the CT-Augmented SEPs are useful outside of the SchoolWide Labs project. It includes guidelines for researchers and curriculum designers.

Tying the definition of computational thinking to the science and engineering practices represents a low barrier of entry for science teachers. Instead of another set of standards to learn, such as those developed by Weintrop and colleagues [159], this definition begins with familiar content. It works towards understanding how to integrate computational thinking into their classrooms. The text of the definition and sensor-specific instantiation call out activities students are doing that represent engagement with the practice. Focusing on what students are doing allows teachers to identify when their students are engaging in computational thinking more easily.

Researchers who want to integrate computational thinking into science classrooms can create their own instantiation of the CT-Augmented SEPs. Researchers can specifically highlight how the computational tools support the CT-Augmented SEPs and explore how students exhibit computational thinking in lessons that do not rely on the technology. For example, when a combination of unplugged activities and computational simulations serves as the integration medium, the CT-Augmented SEPs can be modified to describe how the two concepts work together to integrate computational thinking.

Settling on one framework for integrating computational thinking into science, allows the field to develop a shared understanding of how to integrate computational thinking into science. One definition makes it easier for researchers to test materials in the classroom. The CT-Augmented SEPs are general enough to support the integration of computational thinking with or without computational tools, a shortcoming of the Computational Thinking in Science and Mathematics Taxonomy [159].

Curriculum developers who want to develop units aligned to the NGSS that also use technology similar to the technology used by scientists in the real world can use the CT-Augmented SEPs to integrate the technology deeply. If the technology already has a set of CT-Augmented SEPs developed, the designers can utilize them as they construct the unit. If there is not a set of CT-Augmented SEPs, curriculum developers can work to create a new instantiation of the CT-Augmented SEPs. When curriculum developers utilize the CT-Augmented SEPs, they consist of a uniform set of standards familiar to science teachers.

Separating the sensor-specific instantiation from the definition of the CT-Augmented SEPs allows researchers and curriculum developers that use other mediums for CT-Integration (e.g., 3D printing, computational models, and simulations) to create their own instantiation of the CT-Augmented SEPs. Relying on a similar base definition for computational thinking can allow for the integration of different kinds of technology into science classrooms, all while adhering to the Next Generation Science Standards [87].

This chapter presented a new definition for integrating computational thinking into science instruction through augmenting the science and engineering practices with computational thinking. The goal of CT-Augmented SEPs is to present computational thinking as an approach to problem-solving that applies to scientific inquiry using a wide variety of computational tools.

Chapter 7

Future Work

This chapter outlines some immediate future goals of SchoolWide Labs for the next three design cycles. Section 7.1 introduces a revision to the sensor immersion storyline described in Chapter 5 through the use of the "Use-Modify-Create" framework [91] that explores how to support students to build more in-depth understanding about the programmable sensor technology. Section 7.2 describes how the focus of the CT-Integration Cycle moves beyond the Anchoring Phenomenon Routine and the introduction of sensor technology to additional classroom routines and the inclusion of computational thinking in these routines. The chapter concludes with a discussion of the role of "place" in the development and implementation of storylines in Section 7.3.

7.1 Revision to the Sensor Immersion Storyline

The section serves two purposes. One is to outline a deeper sensor immersion experience with the goal of increasing students' knowledge around using the programmable sensor technologies for scientific inquiry. The second is to describe a potential vertical progression of the sensor immersion over a three year period. As more teachers join the SchoolWide Labs project, cohorts of teachers at specific schools are beginning to develop. To prevent students from experiencing the same sensor immersion unit again, the researchers and teachers have discussed the potential for additional sensor immersion units building on what students have learned previously. The redesign of the sensor immersion unit takes place over three consecutive weeks or one week at the beginning of sixth, seventh, and eighth grade (progression sequence). This revision provides both a more in-depth experience for teachers who have additional time in their schedules (such as STEM teachers) and the progression sequence for schools that have multiple teachers implementing the CT-integrated units.

The “Use-Modify-Create” framework introduced by Lee and colleagues [91] serves as the basis for the revision of the sensor immersion unit. The “Use-Modify-Create” framework describes a set of scaffolds representing three phases of engaging in computational thinking. *Use* refers to students interacting with previously created computational artifacts. For example, students use a simulation or collect data using a preprogrammed data collection device. *Modify* describes how students change existing computational artifacts (e.g., altering the code on the programmable sensor technology to collect sound data rather than temperature data). Finally, *Create* represents a time when students have developed sufficient computational thinking skills to create artifacts from scratch. The goal is for students to spend approximately one week on “Use”, one week on “Modify”, and one week on “Create”.

“Use-Modify-Create” has been used in several computer science activities designed for K-12 students [91, 90] including activities integrating into mainstream science classes [95]. This method has not only been successful in scaffolding students’ participation in computational thinking activities but also in supporting the teachers who are implementing this instructional strategy who may not have a strong computing background [95].

The “Use-Modify-Create” framework can serve as a strategy for students to develop ownership over computational thinking as a problem-solving technique [91]. This strategy has the potential to support one of the goals of the project where students understand that they are engaging in computational thinking and see it as an approach in their problem solving toolkit[1] .

7.1.1 Use

The week focused on “Use” begins in a similar fashion to the original sensor immersion storyline. Students explore classroom data displays and develop a set of questions about the

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[1] This is one of the student outcomes from the conjecture map in Chapter 4 in Figure 4.2.

displays. Also, they create their first model of how the data display works. The teachers create the classroom data displays for the revision during the summer workshop.

The significant modifications occur on the second and third days when students explore the pieces of the data display. This time they do not follow a set of tutorials to program the micro:bit to create their own mini data displays, but rather explore preprogrammed mini data displays. Students examine the code to determine how their interaction with the sensors affects the appearance of the display. Students update their models based on what they learned from exploring the preprogrammed data displays. Days four and five follow similar patterns to the original sensor immersion unit.

This week-long unit no longer focuses on students creating their own mini data displays to help them understand the programmable sensor technology. Instead, it focuses on how the classroom data display works through an examination of other preprogrammed mini data displays. For these mini data displays, students explore how there interactions with the sensor system influence the displays by examining the code.

7.1.2 Modify

This section describes two slightly different pathways either through an immediate continuation of the sensor immersion unit, or a subsequent grade level implementation of the sensor immersion unit.

Week Two. Students move beyond “using” the classroom and mini data displays to modifying the programs to collect and display information differently. For example, students may choose to collect information using a different sensor or display information in a new way, using different colored lights or sounds. Students continue to update their models throughout the week. The week concludes with a gallery walk where students display their modifications and the corresponding programs. Students engage in a discussion around what modifications they made, how they made the modifications, and difficulties they had in making their modifications. Building on the brainstorm session during the previous week, students add new ways scientific inquiry can use the programmable sensor technology.

Seventh Grade. The main difference between the continuation and the new year is that a new model has to be created instead of updating an original model. The first day revolves around students asking questions about a new classroom data display and developing an initial model. On the second day, students spend time "using" preprogrammed classroom data displays to remind students how they work. The next three days follow a similar pattern described above, with students modifying the existing mini data displays.

7.1.3 Create

This section describes two slightly different pathways either through an immediate continuation of the sensor immersion unit or a subsequent grade level implementation of the sensor immersion unit.

Week 3. Students are set free to create their own mini data displays. However, students do not get to start building and programming immediately. Students first make a plan for what they want their data display to show, why they are interested in creating that specific data display, and what they hope the data display will tell them. Students view and interact with each other's displays to develop a general model of how the data displays work. Building on the brainstorm session during the previous week, students add new ways that scientific inquiry can use the programmable sensor technology.

Eighth Grade. The main difference between the continuation and the new year is that students examine a new classroom data display and set of mini data displays to remind themselves of how to "use" the programmable sensor technology. The remaining time follows the sequence described above, with students creating their own mini data displays.

This section outlined a potential modification to the sensor immersion unit based on the "use-modify-create" framework [91]. This is not a complete modification, but merely an idea for potential modification. The refinement of the sensor immersion storyline will address questions regarding how to support coherence in the "use-modify-create" framework and how to drive the unit forward using student questions.

Additionally, the subsequent units will include scaffolds that integrate the programmable sensor technology in order to support students progressing from *users* to *modifiers* to *creators*. For example, if students participated in the "Use" sensor immersion unit, then other subsequent units will gradually have them progress from *users* to *modifiers*.

7.2 Moving Beyond the Anchoring Phenomenon Routine

For the first three design cycles, the main focus of the professional development workshops and the corresponding classroom implementation has been the launch of the lesson and the use of the programmable sensor technology. The lesson's launch revolves around the teacher and students engaging in the anchoring phenomenon routine where students are introduced to the phenomenon and generate a set of questions that drive the rest of the lessons. The other focus area is the first use of programmable sensor technology and how students engage with the technology. These lessons were videotaped for analysis by the research team and use during the reflection workshops in the CT-Integration Cycles.

The Anchoring Phenomenon Routine is one of five classroom routines that support the implementation of units based on storylines [126]. Another routine is the Navigation Routine, which takes place at the beginning and end of each lesson to orient students to what they have learned and what they need to figure out next [126]. The Navigation Routine involves whole-class discussion and presents a new avenue for exploration.

As the project moves into its next phase, the focus shifts to classroom discourse around whole-class discussion and the usage of productive student talk. Specifically, the goal is to focus on how students can engage in productive communication around computational thinking. Productive student talk focuses on making learning equitable for all students [101]. Talk is a way for students to engage with the CT-Augmented Science and Engineering Practices by engaging in the sharing of ideas and being active listeners in the discussion.

When engaging in productive student talk in Next Generation Science Standards aligned units, students are the drivers of the discussion, and the teacher serves as a facilitator [32]. Students are listening and responding to one another, building on each other's ideas, asking questions, and providing critiques to move the class's knowledge forward [101]. NGSS aligned high school biology storylines created by the inquiryHub team at the University of Colorado Boulder[2] introduce four discussion types that support the implementation of storylines: Generating and Prioritizing Questions, Initial Ideas, Building Understanding, and Consensus Building.

Generating and Prioritizing Questions Discussions focus on students observing a phenomenon and creating a set of questions around that phenomenon. After the students create the questions, they group related questions and determine an order to investigate the question. This order in which the students organize the questions depends on how the questions relate to one another (e.g., figuring out what mold is before determining whether or not mold can grow in the school). This discussion occurs during the anchoring phenomenon routine and at the end of each investigation.

Initial Ideas Discussions involve students sharing their prior knowledge related to the phenomenon or question under investigation. The point of these discussions is not to determine which ideas are correct but simply to explore how students initially understand the phenomenon. The ideas will be explored as students research and investigate the phenomenon and be supported or contradicted by the evidence collected. These discussions occur before students begin investigating their questions often at the beginning of class.

Building Understanding Discussions revolve around students sharing ideas about the questions based on what they figured out during research and investigations. This is when students pool the knowledge they collected to build understanding as a group around the questions and the

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[2] https://www.colorado.edu/program/inquiryhub/

phenomenon. A disagreement between groups most often occurs during this discussion because students are still figuring out the answers to their questions. These disagreements do not need to be resolved but instead explored in future lessons. These discussions most often occur at the end of an investigation or at the beginning or end of the lesson to remind students what they have learned and what more information they need.

Consensus Building Discussions occur once students have built sufficient knowledge around the questions they are investigating. Students work together to determine a common understanding of the answer to those questions and how they help them build knowledge around the phenomenon. These discussions resolve disagreements raised during the *Building Knowledge Discussions*. The conclusion from these discussions may result in an updated class consensus model of the phenomenon. These discussions take place after a row in the storyline, most often, at the end of a class period. However, they may also appear at the beginning of the class period to have students review their findings from the day before.

These discussion types often involve students engaging in the science and engineering practices both during the discussion itself (e.g., Asking Questions and Defining Problems, Engaging in an Argument from Evidence, Constructing Explanations and Designing Solutions, Obtaining, Evaluating, and Communicating Information) and as support for the discussion (e.g., Developing and Using Models, Planning and Carrying Out Investigation, Analyzing and Interpreting Data, and Using Mathematics and Computational Thinking). Thus, they provide an outlet for the observation of the CT-Augmented Science and Engineering Practices.

Of note is that these discussions often occur at the beginning and end of a lesson as part of the *Navigation Routine* [126].

The Navigation Routine takes place at the beginning of a lesson to remind students what they learned the day before and what they need to figure out today, and at the end of the lesson to summarize the knowledge built during the lesson and to plan for what more they need to figure out tomorrow.

The Discussion Types and the Navigation Routine serve as new focal points for the CT-

Integration Cycle. Each unit highlights where different discussion types are likely to occur along with the corresponding CT-Augmented Science and Engineering Practices. This knowledge will allow for targeted videotaping of lessons. An essential piece of the problem solving cycle [17] is that teachers have a shared implementation experience. All units include these Discussion Types and Navigation Routine.

7.3 Place

This section outlines the representation of place in the four storylines, the challenges of including a focus on place, and how the Navigation Routine described in the previous section can address some of those challenges.

Grounding investigations in students' schools and local communities was an original goal of the project representing a possible way to engage underrepresented groups [120, 4, 77, 154]. Place was a focal point of the Mold Growth Storyline, where students used the sensor technology to investigate *their school* for the conditions for mold growth. Initial findings from the implementation of that unit found the idea of investigating the school to be an engaging concept for students [50, 49]. The mold growth unit contained a significant amount of computational thinking for its short duration of one week but lacked in science content.

The next design cycle led to the creation of the maglev train storyline. The tie-in to place became more tenuous since it involved students exploring what would happen if the community decided to build a maglev train. Building a maglev train in the community was only discussed extensively during the first and last lesson of the unit, with many teachers not mentioning it at all in other lessons, or skipping the last lesson entirely. This was evident in the results from the survey question, **What we did in class today matters to people in my city because: (circle the option that best describes your feelings)** with options: *This material is important and people should know about it*,*This material could improve the lives of people in my city*, *What we did today doesn't matter to people in my city.* This question was asked three times throughout the unit: after lesson 1, after lesson 3, and after lesson 6 with more students answering *What we did today doesn't* *matter to people in my city* for the second and third survey [48]. This dropoff in relevance of the material to the students was not evident in a similar question asked during the mold growth unit.

For the third design cycle, a goal was to attempt to foreground place more intentionally in the lessons. Students explore creating compost to grow their own food. This addresses two issues the students face: 1) the fact that most students served by this project live in food deserts and 2) the poor quality of the soil in the area. While the unit's implementation is incomplete, initial discussions with teachers revealed the lack of student understanding about living in a food desert, and the limited relevance composting brings beyond the "cool" factor of having worms and dirt in the classroom. This seeming lack of relevance surprised both the teachers and the research team. While the compost unit involved students investigating compost bins in their classrooms, the local tie required students to see *beyond* their classroom. Further examination of the data is required to see if patterns similar to those in the maglev train unit emerge in the unit's perceived relevance and how teachers articulate the concept of place throughout the unit.

Students built data displays to communicate information about the classroom environment during the sensor immersion unit. Here 88% of students responded that *this material could improve the lives of people in my city* and/or *This material is important and people should know about it* which indicates the potential relevance of the unit to the students. The sensor immersion unit is grounded in students' place in a similar way to the mold growth unit.

The representation of place in the mold growth unit and sensor immersion units differs from the representation of place in the maglev train and compost units. In the former units, the investigations involve students collecting data about their school or their classroom. In contrast, in the latter units, the investigations involve students collecting data from experiments that are more abstractly related to the community or school. The direct connection to the school seems to make the relevance of place more evident to the students and does not rely as much on teachers emphasizing the relevance of place.

Finding phenomena rich in science content, providing an opportunity for sensor usage, and being grounded in students' place is particularly challenging. While some phenomena exist that support data collection in the school, others have to define the notion of place more broadly, such as imagining the construction of a maglev train in the community. To integrate place requires a continued commitment to highlighting place throughout the unit and creativity in using programmable sensor technology.

The Navigation Routine represents an opportunity to provide continuity to the concept of place throughout the unit. If the questions and investigations relate to topics existing in the school or community, the Navigation Routine can continuously raise these issues. Even if the students are collecting data from an investigation that does not involve the school, the Navigation Routine allows them to step back and examine the bigger picture. Engaging in the Navigation Routine reminds the students of how what they are trying to figure out relates to the overarching phenomenon.

This chapter outlined three areas of immediate future work as SchoolWide Labs enters its fourth design cycle. Modifications will be made to the sensor immersion unit to support students' understanding of the functionality of the programmable sensor technology and how the sensors can serve as a tool for scientific inquiry. The emphasis of the CT-Integration Cycle will extend from the Anchoring Phenomenon Routine and the introduction of the programmable sensor technology to the Navigation Routine and Discussion Types that utilize the CT-Augmented Science and Engineering Practices. Lastly, the Navigation Routine will be explored as a potential mechanism for highlighting the relevance of place throughout the unit.

Chapter 8

Conclusion

This chapter addresses the limitations of the research, details two ideas for future work, and describes the main takeaways from the first three design cycles of the SchoolWide Labs project. The chapter concludes with a discussion about how this works advances the field of computational thinking education. This future works differs from the immediate future work described in Chapter 7 in that it extends beyond the scope of the SchoolWide Labs project.

8.1 Limitations

SchoolWide Labs is an exploratory project that examines how to successfully design tools and professional development materials and workshops to support teachers in integrating computational thinking into their classrooms.

The project's focus has been on student experience during the implementation of the units integrated with computational thinking and on teacher experience participating in the CT-Integration Cycle. The reflection workshops highlight teachers views' on student learning, and Chapter 5 explores the use of student models to assess learning in the sensor immersion unit. However, there is not yet a rigorous assessment of student learning. Along the same lines, no rigorous assessment of teacher learning exists.

The number of teacher participants is small, with the largest cohort of 10 teachers participating in the third design cycle. This small group represents teachers interested in co-designing units that integrate programmable sensor technology into the classroom but are not necessarily representative of all the middle school science and STEM teachers in Denver Public Schools.

8.2 Future Work

Two areas for future research beyond the scope of SchoolWide Labs are to explore how computational thinking can augment the crosscutting concepts [87] and to apply the storyline instructional design technique to support guided inquiry in computer science education.

Crosscutting concepts represent how students think about problems across different scientific disciplines. These concepts are *patterns*, *cause and effect*, *scale, proportion, and quantity*, *systems and system models*, *energy and matter*, *structure and function*, and *stability and change*. Crosscutting concepts are traditionally the most difficult dimension of science learning to define and recognize in the classroom. Integrating computational thinking into the crosscutting concepts would allow for more depth in the integration of computational thinking.

Storylines can be used as an instructional design technique to present computer science content to K-12 students in a coherent manner built around students' questions. Design challenges in science classrooms utilize this strategy to engage students deeply in the engineering practices portion of the science and engineering practices [153]. In computer science education, the challenge is redefining the anchoring phenomenon for the unit. The definition of phenomenon can become broader and move beyond the natural phenomena that science storylines use as anchors. This expanded definition can potentially allow for place to play a more focal role in the storyline. For example, in India, noise sensors were used to trigger the red traffic light timer to reset when there was too much noise[1] . Grounding the storylines in students' local context can provide them an understanding of the larger purpose of why they are learning computer science.

8.3 Conclusions

This dissertation explored integrating computational thinking into required middle school science and STEM classes using programmable sensor technology over three year-long design cycles.

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[1] https://twitter.com/MumbaiPolice/status/1223090017397960705

These design cycles focused on developing programmable sensor technology, creating productive integration tools, and designing a set of professional development workshops (referred to as CT-Integration Cycle).

The first two design cycles revealed two main challenges to the success of integrating computational thinking into science classrooms. First, students are unfamiliar with programmable sensor technology. This unfamiliarity results in teachers rather than students motivating the use of the programmable sensor technology and prevents students from engaging independently with the programmable sensor technology in their scientific inquiries. Second, the Computational Thinking in Science and Mathematics Taxonomy [159] provided a suitable initial understanding for the integration of computational thinking into science but presented a challenge when exploring how to integrate computational thinking outside of using the programmable sensor technology. These two challenges influenced the development of the third design cycle.

A new sensor immersion unit implemented at the beginning of the school year to introduce students to the programmable sensor technology addresses the first challenge. This unit focuses on students building knowledge about the programmable sensor technology and how they can support their scientific inquiry. This knowledge allows them to engage independently with the programmable sensor technology in their scientific investigations.

To address the second challenge, Chapter 6 introduced a strategy for creating a new definition for integration, relying on augmenting the Science and Engineering Practices [147] with computational thinking using *computational approaches*, *computational processes*, and *computational tools*, referred to as CT-Augmented Science and Engineering Practices. Computational thinking is a problem-solving technique that may or may not involve computational tools. This enables its seamless integration into lessons that do not rely heavily on computational tools.

The new definition provides researchers with concrete examples of computational thinking tied to practices that are familiar to the partner teachers. The new definition is useful for the development of curriculum and professional development workshops. Additionally, other researchers focused on integrating computational thinking into science can instantiate the definition with their own medium of integration.

8.4 Moving Computational Thinking Forward

This dissertation explored a novel way of designing middle school science units that integrate computational thinking. SchoolWide Labs brings together teachers and researchers through a Research-Practice Partnership to design and enact middle school science units that integrate computational thinking through programmable sensor technologies. Partnerships like this one can help support the widespread adoption of computational thinking activities. Researchers are not undertaking a boutique intervention in one or two classrooms, but rather working at the district level or higher to facilitate systematic change. Creating and maintaining these partnerships presents an opportunity for more K-12 schools to include computer science and computational thinking throughout their curriculum.

When integrating computational thinking into other subjects or teaching computational thinking more directly in a computer science or STEM class, researchers and curriculum developers should draw on the current best practices in K-12 education. For this project, that meant drawing on the Next Generation Science Standards [87] and instructional design techniques [123] proven successful for implementing these standards. Storylines [133, 122, 141] provide the blueprint for coherent, guided inquiry representing a middle ground between the step-by-step tutorials or tinkering [12]: two strategies often employed to teach computational thinking and computer science. Storylines promote learning about and using technology with a purpose, similar to how scientists in the real world engage with technology.

The programmable sensor technologies present a low-cost way to engage students in computational thinking that involves more than just sitting in front of a computer screen. Students can get out, move, and explore the world around them like real scientists. They are not subject to curated data sets or simulations, but rather can explore and collect their own data. The programmable sensor technologies provide a new medium to engage students in computational thinking.

Drawing on the literature from education and the learning sciences provides a rich body of work to utilize during curriculum design. It challenges researchers to see the similarities between what they are trying to do and work already completed in different areas. Since many fields of study increasingly rely on computational thinking [44], the disciplines must integrate computational thinking throughout.

Another key feature of the SchoolWide Labs project is that teachers and researchers collaboratively design the units that are then implemented by the teachers themselves. This co-design process allows for the creation of a unit with more potential for success during implementation than if researchers alone created the unit. Co-design also creates a professional community for the teachers and allows them to come together to work on the project. Teachers recruit other teachers from their schools to join the project, and the co-design team provides a community for the STEM teachers. Many STEM teachers are the only STEM teacher at their school and often do not have the opportunity to work with other teachers to develop curriculum.

Lastly, it is in the field's best interest to settle on a definition and framework for computational thinking similar to how other subject areas have a set of standards for K-12. While this dissertation presented such a possibility specifically for science, it is essential to agree on a standard framework. When many different frameworks and standards exist, it is difficult for practitioners to know which one to use. This makes it challenging for units and curriculum to achieve widespread adoption.

This dissertation introduces a guided inquiry curriculum designed with teachers as part of a broader partnership between a school district and a research university. Building these relationships is critical to bringing computational thinking to all students.

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Appendix A

Reflections, Interviews, and Surveys

A.1 Written Teacher Reflections

A.1.1 Cycle One: 2017/2018 School Year

Professional Workshop 3

Morning

(1) What are your reflections on your experience with the sensors+mold unit in the classroom?

(2) Write down any questions you have for our group to discuss/ investigate.

Afternoon

(1) What are your reflections on the extent to which students' engaged in computational thinking during the unit?

(2) What kinds of CT did they engage in? Consider the SEET Data on science, engineering, and CT practices and write any reflections you have about how students reported their engagement in science practices and CT practices.

(3) Write down reflections on the use of sensors in your classroom

A.1.2 Cycle 2

Summer Workshop Day 1

(1) How do you see Computational Thinking represented the micro:bit exercises you just completed?

(2) What are you thinking and wondering about what CT looks like when it is integrated into middle school science?

(3) What are you thinking and wondering about related to collaborative design of science+CT curriculum?

Summer Workshop Day 3

(1) What about this experience do you value? (be specific)

(2) What concerns do you have about the storyline we are developing? Consider things like the science, technology, activities, implementation, connecting to kids' interest.

(3) How, if at all, has co-design helped you learn and grow as a science or STEM teacher?

Professional Development Workshop Day 2

MagLev Storyline

(1) What are your overall thoughts about the MagLev storyline?

(2) What part(s) of the MagLev Storyline do you most confident about implementing in your classroom?

(3) What concerns do you have about implementing the MagLev Storyline?

Computational Thinking

(1) Has taking part in this project influenced how you view computational thinking? Are these activities we have done in our workshops (or discussions we have had) that have influenced your thinking? How?

(2) What questions do you still have about computational thinking? Can you think of any workshop activities or discussions that would help us address those questions?

(3) What additional supports would be helpful for you to successfully implement CT-integrated instruction using the micro:bits in January?

Additional project participants for next year

Do you have any suggestions for colleagues to join our project next year? (They should teach middle school science/STEM in DPS).

Professional Development Workshop Day 3

Morning Reflections

(1) What are your reflections on your experience with the maglev unit in the classroom? What did you like? What should we change?

(2) In what ways did you rely on the storyline/teacher guide when planning for and teaching the unit? What lesson supports (i.e. teacher guide, activity sheets, etc.) did you find most helpful? Least helpful? Are there any additional supports that you would like to see in a unit?

A.1.3 Cycle Three

Summer Design Workshop June

Part 1: Sensor Immersion Co-Design Experience

(1) What are your thoughts on the sensor immersion experience...

   (a) How well did it support your own learning?

   (b) How well prepared do you feel to facilitate the sensor immersion with your students?

   (c) What do you think your students will learn from this immersion experience, and where might they struggle?

(2) What are your thoughts about participating in the co-designing process we used these past 2 days to develop the tools, resources, and the Sensor Immersion Experience for students? Suggestions for how we could improve this process going forward?

(3) What tools did you think will be most useful when you implement this sensor immersion with your students? Are there additional tools you'd like to have to support CT integration in your classroom?

(4) What else should we do in the August workshops to help prepare for the sensor immersion?

Part 2: NGSS, Unpacking, and Looking Forward

(1) Did you learn anything new these past 2 days about using phenomena driven learning in your classroom?

(2) What are your thoughts about participating in the unpacking process to take a close look at NGSS and Computational Thinking Practices to start creating a storyline?

(3) Did you learn anything new about how phenomena driven learning and CT can be integrated in science?

(4) Do you have suggestions for activities we can do in the August workshops to help prepare for using sensors, CT, and storylines in your classroom?

Summer Design Workshop August

Implementing the Sensor Immersion Storyline

(1) When do you plan to implement the sensor immersion storyline (please list likely dates and class periods)?

(2) Are there modifications you are planning to make (e.g. taking more or less time on the storyline, adding or deleting portions of the storyline)?

(3) Are you comfortable being videotaped implementing this storyline?

(4) What support do you want prior to/during implementing the storyline?

Implementing the Other CT-integrated Storyline

(1) Which storyline(s) are you planning to implement?

(2) (Approximately) when do you plan to implement the other CT-integrated storyline(s)?

(3) Are there modifications you are planning to make (e.g. taking more or less time on the storyline, adding or deleting portions of the storyline)?

Storyline Development and Prep

(1) Thinking about the storyline development (co-design) process, what are your overall thoughts?

  (a) What about this experience do you value?

  (b) What has this process helped you to learn?

  (c) What concerns or suggestions do you have for improving the process?

(2) Were the rehearsals helpful? How?

(3) Do you have any suggestions for our upcoming workshops this fall?

Professional Development Workshop Two

Sensor Immersion Reflection

(1) What did you learn about teaching a unit that highlights CT?

(2) If you were to teach the sensor immersion unit again, what would you do differently?

(3) If you were explaining what CT is to someone else, how would you define CT?

Professional Development Workshop Three

CT infused SEPs

(1) What did you learn from co-designing the CT infused SEPs?

(2) In what ways might the CT infused SEPs and related examples be useful as you plan and implement the storyline(s)?

(3) Would you find it helpful to continue to co-design the additional CT infused SEPs in upcoming workshops?

Planning and Rehearsals

(1) In what ways might the four discussion types be helpful as you plan and implement your storyline?

(2) What did you learn from engaging in the process of planning, rehearsing, providing feedback, etc.?

(3) What suggestions do you have for improving the process?

Logistics

(1) What storyline(s) do you plan on implementing this spring? When (if possible please provide a specific date)?

(2) Are you planning on taking part in the project again next year?

A.2 Teacher Interviews

A.2.1 Cycle One

Pre/Post Mold Growth Storyline Implementation Teacher Interview Protocol

Thinking about the beginning of your lesson today

(1) How do you think your opening went?

(2) Do you feel like students were in the driver's seat?

Thinking about the main activity your students did in class today

(1) Did it go as you expected?

(2) In what ways did your students demonstrate computational thinking skills?

(3) Did they engage with the sensors as you expected? (if appropriate)

Thinking about the conclusion of your lesson today

(1) How did you feel the conclusion of the lesson went?

(2) Did the students seem to get where you hoped they would be by the end of the lesson?

(3) Do they have ideas about where to go next? (first lesson only)

(4) How do you feel about the way the unit ended? (last lesson only)

Thinking about the lesson overall

(1) What do you think your students learned or took away from this lesson?

(2) How much did you rely on the storyline/teacher guide when planning for and teaching this lesson? How did you modify it for your students?

(3) Do you have suggestions for other teachers who might teach this lesson next year?

(4) What additional supports should we build in for other teachers who might teach this lesson?

Last lesson only

(1) How did you think the unit went as a whole? Are there things you would do differently if you were to teach it again?

(2) How did you feel about the use of sensors in the unit? Were there any surprises? Was anything particularly challenging?

(3) What do you think your students learned or took away from the unit as a whole?

A.2.2 Cycle Two

Post Maglev Train Storyline Implementation Teacher Interview, 30 min total (10 min per section)

Maglev Unit Overall

(1) How did you think the maglev unit went as a whole?

(2) What do you think your students learned or took away from the unit?

(3) Are there things you would do differently if you were to teach it again?

(4) How much did you rely on the storyline/teacher guide when planning for and teaching the unit?

(5) How did you modify it for your students?

(6) What supports included with the storyline were most useful?

(7) What additional supports should we build in for other teachers who might teach this lesson?

(8) Do you have suggestions for other teachers who might teach this lesson next year?

Student engagement in the unit

(1) How engaged were your students in the unit compared to how engaged they usually are?

(2) What elements of the unit supported student engagement?

(3) Comparing this unit to the mold unit, which do you think was more engaging and why? (Courtney and Taylor only - follow up with something about investigating your own school versus proposing a maglev train in Denver)

(4) Were there parts of the unit that did not engage your students as much as you would have liked?

(5) How interested were your students in the anchoring phenomena?

(6) Did the unit sustain your students' interest throughout?

(7) Were there parts that were less student driven than you expected?

Use of Sensors and CT practices

(1) Were your students successful in collecting and using data/evidence to construct well-reasoned and accurate explanations?

(2) How did you feel about the use of sensors in the unit? Were there any surprises? Was anything particularly challenging?

(3) Did focusing on CT practices (data analysis and programming) add value to your students' science learning in the unit? How/what did they help your students learn?

(4) What have you learned from using this unit that will help you in teaching future concepts using 3D Learning and/or CT practices?

(5) For next year, Alex is thinking of creating a one-two week unit that showcases sensor use related to the SEPs in August or September, with the idea that teachers would implement this at the beginning of the school year. The idea behind this is to help students learn about various sensors as tools to investigate phenomenon. How interested would you be in implementing this with your students next year? Do you have any ideas or concerns?

If time look at ideas for upcoming PDs

What do you want to talk about with other teachers at the next PD about the maglev unit/use of sensors?

A.2.3 Cycle Three

Post Sensor Immersion Storyline Implementation Teacher Interview, 45 min total

Sensor Immersion Storyline Overall

(1) How did you think the Sensor Immersion unit went as a whole?

(2) What do you think your students learned or took away from the unit?

(3) Are there things you would do differently if you were to teach it again?

(4) How much did you rely on the storyline/materials when planning for and teaching the unit?

(5) How did you modify it for your students?

(6) What supports included with the storyline were most useful?

(7) What additional supports should we build in for other teachers who might teach this lesson?

(8) What have you learned from using this unit that will help you in teaching future concepts using 3D Learning and/or CT practices?

Reflecting back on each day of the storyline

- Day 1
    (1) How well did the anchoring phenomenon engage your students?
    (2) Were your students successful in generating questions about the sensor systems that could be investigated?
    (3) Were your students able to create initial models to explain how they understand how the classroom sensor system and data display works?
- Day 2/3
    (1) How engaged where your students in the sensor investigations and programming?
    (2) How did the experiences using the sensors and creating data displays improve your students' models?
    (3) Were there any unexpected challenges with students using the sensors?
    (4) Were there any surprises?
- Day 4
    (1) How well were your students able to communicate what they discovered during the sensor investigation?
    (2) How did the sharing out process go? What are some ways they shared? Did other students respond to other groups shareout?

  (3) Do you feel that your students are ready to use the sensors in other scientific investigations?

- Day 5
  1. What feedback do you have about the assessment?
  2. Which version did you use?
  3. Did your students have any difficulty with the assessment?
  4. How are you planning on using the students' assessment data?

A.3 Teacher Survey

A.3.1 Cycle 1

(1) Demographic Information (Name, School, Subject, Grade, Years Experience)

(2) What NGSS training or teaching experience do you have?

(3) How well prepared do you feel to support students developing the following computational thinking skills [Not adequately prepared, somewhat prepared, fairly well prepared, very well prepared]

  (a) Collecting, manipulating and visualization data
  (b) Creating data
  (c) Developing computational models
  (d) Analyzing and modifying computational models
  (e) Computer programming
  (f) Explaining the different layers of a system and how the layers interact and relate

(4) Describe your computer science or programming experience

  (a) I have a computer science background

   (b) I have completed projects using programming
   (c) I have done an hour of code activity or something similar
   (d) None

(5) Describe any computer science or programming activities you have done with students.

(6) How confident are you that you can [Very confident, Somewhat confident, In the middle, Somewhat unsure, Not at all confident]

   (a) Get students to ask questions at the beginning of a unit that guide the lessons that follow?
   (b) Work with students to motivate the next step in investigating a phenomenon, rather than just telling them the next step?
   (c) Help students use practices to figure out pieces of core science ideas?
   (d) Push students to go deeper to revise their explanatory models of phenomena?
   (e) Help students put pieces together of disciplinary core ideas and crosscutting concepts?

(7) For each of the statements below, state the degree to which you agree or disagree. [strongly disagree, moderately disagree, slightly disagree, slightly agree, moderately agree, strongly agree]

   (a) Teachers should have students do interesting hands-on activities, even if the activities do not relate closely to the concept being studied.
   (b) Students need to discuss their thinking with each other in order to learn science concepts.
   (c) Teachers should provide students with opportunities to apply the concepts they have learned in new or different contexts.
   (d) Hands-on/laboratory activities should be used primarily to reinforce a science idea that the students have already learned.

(e) At the beginning of instruction on a science idea, students should be provided with definitions for new scientific vocabulary that will be used.

(f) Students' ideas about a science concept should be deliberately brought to the surface prior to a lesson or unit so that students are aware of their own thinking.

(g) Teachers should provide students with the outcome of an activity in advance so students know they are on the right track as they do the activity.

(h) Students should do hands-on or laboratory activities, even if they do not have opportunities to reflect on what they learned by doing the activities.

(i) Students should have opportunities to connect the concept they are studying to other concepts.

(j) Teachers should provide students with opportunities to connect the science they learn in the classroom to what they experience outside of the classroom.

(k) Teachers should explain an idea to students before having them consider evidence that relates to the idea.

(l) Students should know what the results of an experiment are supposed to be before they carry it out.

(m) When students do a hands-on activity and the data don't come out right, teachers should tell students what they should have found.

(n) It is better for science instruction to focus on ideas in depth, even if that means covering fewer topics.

(8) The biggest questions I have going into this year regarding implementing sensors in my class are:

(9) One way I hope to grow in my science teaching this year is....

A.3.2 Cycle 2

Summer Workshop

(1) Demographic Information (Name, Gender, Ethnicity, Race, Disability, School, Subject, Grade, Years Experience)

(2) What NGSS and/or STEM training experience do you have? (e.g., I attended an NGSX workshop in June 2018 or I attended a workshop about X at Sparkfun)

(3) How well prepared do you feel to support students developing the following computational thinking skills [Not adequately prepared, somewhat prepared, fairly well prepared, very well prepared]

  (a) Collecting, manipulating and visualization data

  (b) Creating data

  (c) Developing computational models

  (d) Analyzing and modifying computational models

  (e) Computer programming

  (f) Explaining the different layers of a system and how the layers interact and relate

(4) What is your computer science or programming experience and comfort level. Check all that apply.

  (a) I have a computer science background

  (b) I have completed projects using programming

  (c) I have done an hour of code activity or something similar

  (d) I am very comfortable doing computer science or programming activities with my students

  (e) I am very comfortable doing hour of code or something similar with my students

   (f) I am very comfortable figuring out the computer science or programming aspects of a project alongside my students
   (g) None

(5) How confident are you that you can [Very confident, Somewhat confident, In the middle, Somewhat unsure, Not at all confident]

   (a) Get students to ask questions at the beginning of a unit that guide the lessons that follow?
   (b) Work with students to motivate the next step in investigating a phenomenon, rather than just telling them the next step?
   (c) Help students use computational thinking practices to figure out pieces of core science ideas?
   (d) Work with students to motivate the need to use sensors, microbits, and computational thinking in their investigations?
   (e) Push students to go deeper to revise their explanatory models of phenomena?
   (f) Help students put pieces together of disciplinary core ideas and crosscutting concepts?

(6) For each of the statements below, state the degree to which you agree or disagree. [strongly disagree, moderately disagree, slightly disagree, slightly agree, moderately agree, strongly agree]

   (a) Teachers should have students do interesting hands-on activities, even if the activities do not relate closely to the concept being studied.
   (b) Students need to discuss their thinking with each other in order to learn science concepts.
   (c) Teachers should provide students with opportunities to apply the concepts they have learned in new or different contexts.

  (d) Hands-on/laboratory activities should be used primarily to reinforce a science idea that the students have already learned.

  (e) At the beginning of instruction on a science idea, students should be provided with definitions for new scientific vocabulary that will be used.

  (f) Students' ideas about a science concept should be deliberately brought to the surface prior to a lesson or unit so that students are aware of their own thinking.

  (g) Teachers should provide students with the outcome of an activity in advance so students know they are on the right track as they do the activity.

  (h) Students should do hands-on or laboratory activities, even if they do not have opportunities to reflect on what they learned by doing the activities.

  (i) Students should have opportunities to connect the concept they are studying to other concepts.

  (j) Teachers should provide students with opportunities to connect the science they learn in the classroom to what they experience outside of the classroom.

  (k) Teachers should explain an idea to students before having them consider evidence that relates to the idea.

  (l) Students should know what the results of an experiment are supposed to be before they carry it out.

  (m) When students do a hands-on activity and the data don't come out right, teachers should tell students what they should have found.

  (n) It is better for science instruction to focus on ideas in depth, even if that means covering fewer topics.

(7) The biggest questions I have going into this year regarding implementing a storyline with micro:bits and sensors in my class are:

(8) One way I hope to grow in my science or STEM teaching this year is...

First Professional Development Workshop One

Levels of Use Survey[62]

- 0. Nonuse - I am not taking any action in regard to using this in my classroom
- 1. Orientation - I am seeking more information on using this in my classroom.
- 2. Preparation - I am preparing to use this in my classroom.
- 3. Mechanical Use - I am using this in my classroom, but it is not always coordinated with my course of study.
- 4. Refinement - I am making changes in my use of this in my classroom to increase outcomes.
- 5. Integration - I am making deliberate efforts to help others to use thin in their classroom(s).
- 6. Renewal - I am seeking more effective alternatives to the already established use of this in my classroom.

Please help us understand you current level of use of the following in your classroom. Please be as honest as possible in your evaluation of you use of each of the following.

(1) Phenomena Driven 3D Learning/ Incremental Sensemaking

(2) Science and Engineering Practices (SEPs)

(3) Crosscutting Concepts (CCCs)

(4) CT Data Practices where students **collect** and **manipulate**; data to create **analyse** and **visualizations**.

(5) CT Computational Problem Solving Practices where students **determine the appropriate computational tools**, **program**, **assess different solutions to problems**, and **debug**.

(6) Classroom discourse around Phenomena and/or Disciplinary Core Ideas (Big Science Ideas)

(7) Classroom discourse around Computational Thinking

Fourth Professional Development Workshop

The original survey from the Summer Workshop combined with the levels of use survey plus the following additional questions for RETURNING teachers.

(1) The biggest questions I have going into the 2019-2020 school year regarding implementing a storyline with programmable sensors in my class are:

(2) One way I hope to grow in my science or STEM teaching during the 2019-2020 school year is....

(3) One way I hope to grow in my CT integration during the 2019-2020 school year is....

The original survey from the Summer Workshop combined with the levels of use survey plus the following additional questions for NEW teachers.

(1) The biggest questions I have going into the 2019-2020 school year regarding implementing a storyline with programmable sensors in my class are:

(2) One way I hope to grow in my science or STEM teaching during the 2019-2020 school year is....

A.4 SEETs (Student Experience Exit Tickets)

A.4.1 Mold Growth Unit

(1) What is your first name? [SEET 1-6]

(2) What is your last name? [SEET 1-6]

(3) What is your teacher's name? [SEET 1-6]

(4) What class period are you in? [SEET 1-6]

(5) Today's lesson made me feel... (check all that apply) [SEET 1,4,6]

  (a) Excited
  (b) Bored
  (c) Confused
  (d) Like a Scientist
  (e) Confident
  (f) Happy
  (g) Sad
  (h) Afraid
  (i) Angry
  (j) Other

(6) What we did in class today [SEET 2,3,5]

  (a) Matters to Me
  (b) Matters to the Class
  (c) Matters to the Community

(7) I asked a question and it got added to our Driving Questions Board (DQB) [SEET 1]

  (a) Yes
  (b) No
  (c) Unsure

(8) I figured out something today that helped us make progress on the questions on the Driving Question board. [SEET 2,5]

  (a) Yes

   (b) No
   (c) Unsure

(9) Today I developed or revised a scientific model. [SEET 2]
   (a) Yes
   (b) No
   (c) Unsure

(10) Today I planned a scientific investigation [SEET 3]
   (a) Yes
   (b) No
   (c) Unsure

(11) I know what we need to investigate next [SEET 2]
   (a) Yes
   (b) No
   (c) Unsure

(12) I have some ideas about how to investigate and answer the questions we have. [SEET 3]
   (a) Yes
   (b) No
   (c) Unsure

(13) I know why we did what we did in class today [SEET 4,6]
   (a) Yes
   (b) No
   (c) Unsure

(14) Today I used tools for systematic data collection, recording, and storage [SEET 4]

  (a) Yes
  (b) No
  (c) Unsure

(15) Today I used data from my investigation to write an explanation or make a prediction for the future [SEET 6]

  (a) Yes
  (b) No
  (c) Unsure

(16) Something I said or did today... (Mark all that apply) [SEET 6]

  (a) Helped someone else in class understand something
  (b) Helped the class make progress toward a question on the Driving Question Board
  (c) Helped answer a question that our group or class had

(17) Using the sensor system to collect data was (Mark all that apply) [SEET 4,5]

  (a) Hard
  (b) Easy
  (c) Frustrating
  (d) Confusing
  (e) Fun

(18) Today I... (Mark all that apply) [SEET 5]

  (a) Determined what data I needed for my investigation
  (b) Cleaned data to get rid of any recordings that did not belong

  - (c) Normalized the data (for example, changed the temperature units)
  - (d) Looked for patterns in the data
  - (e) Analyzed data to see trends or averages
  - (f) Made a data visualization (for example, a graph) to analyze my data
  - (g) Made a data visualization (for example, a graph) to communicate my data
  - (h) Used data to support an argument/explanation

(19) I think my teacher should have us use sensors more often to conduct investigations. [SEET 6]

  - (a) Yes
  - (b) No
  - (c) Unsure

(20) I would recommend using sensors to a friend if they wanted to conduct an investigation. [SEET 6]

  - (a) Yes
  - (b) No
  - (c) Unsure

(21) Gender. I am a....[SEET 1]

(22) Race and Ethnicity. I identify as ... (check all that apply) [SEET 1]

  - (a) African American
  - (b) Latin/Hispanic
  - (c) Native American
  - (d) Asian

(e) White

(23) Andy found mold growing on some bread in his refrigerator, he thought mold could only grow between 70 and 85 degrees Fahrenheit. He was confused. What caused the mold to grow on bread in Andy's refrigerator? [SEET 2]

(a) Andy's bread had a kind of mold species that can grow in cold temperatures

(b) Mold can adapt in cold temperatures in order to grow

(c) If mold has certain kinds of food to eat, like bread, it can grow in a colder temperature

(d) The more food there is in a refrigerator, the easier it is for mold to grow even in cold temperatures.

(24) Your friend designed an investigation to answer the research question: How does the amount of air pollution change throughout the school day in our parking lot? They decide to measure the pollution level between 10-11 am every school day for one week using a sensor that measures several possible pollutants. What is the best piece of advice you could give your friend to make their investigation better? [SEET 4]

(a) Run the sensors for more than one week to collect more data

(b) In addition to pollution, collect data on temperature and humidity

(c) Collect data multiple times throughout the school day not just 10-11am

(d) Collect data on the number of cars in the parking lot between 10-11am each day

(25) Scientists collected data on the yearly growth of 500 trees in Rocky Mountain National Park for the last 10 years. They also collected data on the environment around the trees each year. Their data is summarized in the table below. What explains the relationship between tree growth data and the environmental data? [SEET 6]

(a) Trees grow each year regardless of the environmental conditions.

   (b) The trees need the summer temperature to be in the low 80s and the rainfall to be over 7 inches in order to grow.
   (c) If there are several years in a row with rainfall above 10 inches, the trees will grow at a steady rate.
   (d) Trees need water to grow and in years when there is not a lot of rain, trees do not grow as much.

A.4.2 Maglev Train Unit

(1) Teacher Name, Date

(2) What is your student ID number?

(3) Today in class I felt like a scientist.

   (a) Yes
   (b) No

(4) Today we used the Driving Question Board (DQB) to review what questions we've answered in previous classes.

   (a) Yes
   (b) No
   (c) I don't know

(5) With the help of our teacher, we used the DQB to guide what we did in class today.

   (a) Yes
   (b) No
   (c) I don't know

(6) I understand how what we did in class today ties to the bigger picture for what we're studying in this unit.

  (a) Yes
  (b) No
  (c) I don't know

(7) I have ideas about what questions we should investigate next.

  (a) Yes
  (b) No
  (c) I don't know

(8) What we did in class today matters to me because: (circle one option that best describes your feelings)

  (a) This material is interesting
  (b) What we did today will be useful to me in the future
  (c) What we did today is important to my everyday life and/or people I care about
  (d) It will help me get a good grade
  (e) What we did today doesn't matter to me

(9) What we did in class today matters to people in my city because: (circle the option that best describes your feelings)

  (a) This material is important and people should know about it
  (b) This material could improve the lives of people in my city
  (c) What we did today doesn't matter to people in my city

(10) Did you share any ideas out loud today to the whole class, a small group, or a partner?

   (a) Yes
   (b) No

(11) If you answered yes to the last question, did any of your ideas influence the class or help others?
   (a) Yes
   (b) No

(12) Did any other students share ideas out loud today to the whole class, a small group, or a partner?
   (a) Yes
   (b) No

(13) If you answered yes to the last question, did you learn more in class today because other students shared their ideas or opinions?
   (a) Yes
   (b) No

(14) I am a (write your gender) [First SEET]

(15) I identify as (Circle all that apply) [First SEET]
   (a) White
   (b) Latin@/Hispanic
   (c) African American
   (d) Asian/Asian American or Pacific Islander
   (e) Native American or Alaska Native
   (f) Other (Fill in the blank)

(16) My first language at home is (write the language you speak at home) [First SEET]

(17) Which of these helped you to program your sensor? Circle all that apply. [Second and Third SEET]

  (a) Trial and error
  (b) Sample block code
  (c) Written instructions
  (d) A plan for programming that I created
  (e) Tutorial Video
  (f) Your teacher
  (g) A classmate

(18) If you gave me a new problem, I am confident I could program the sensor to collect data to help me understand the problem. [Second and Third SEET]

  (a) Yes
  (b) No

(19) If you gave me a set of data, I am confident I could create a visual representation (graph, table, chart, etc.) of the data to answer a scientific question or solve a problem. [Third SEET]

  (a) Yes
  (b) No

A.4.3 Sensor Immersion Unit

(1) Teacher Name, Date

(2) What is your student ID number?

(3) What's something you're going to remember from using the sensors?

(4) Write about how sensors can be useful in your everyday life

(5) Write about how sensors can be useful for a friend, a relative, or your community in general

(6) I felt like a scientist when we explored the sensor system.

  (a) Yes

  (b) No

(7) What we did with the sensors matters to me because: (choose all options that describe your feelings)

  (a) This material is interesting

  (b) What we did today will be useful to me in the future

  (c) What we did today is important to my everyday life and/or people I care about

  (d) It will help me get a good grade

  (e) What we did today doesn't matter to me

(8) What we did with the sensors matters to people in my city because: (choose all option that describe your feelings)

  (a) This material is important and people should know about it

  (b) This material could improve the lives of people in my city

  (c) What we did today doesn't matter to people in my city

(9) When investigating the sensors

  (a) I shared an idea and it influenced the class

  (b) I shared an idea but it didn't seem to influence the class

  (c) I did not share an idea

(10) When investigating the sensors

  (a) Someone else shared an idea and it influenced the class

  (b) Someone else shared an idea and it didn't seem to influence the class

  (c) No one else shared an idea

(11) My teacher should have us use sensors more often to conduct investigations.

  (a) Yes

  (b) No

  (c) Unsure

(12) My gender is

  (a) Female

  (b) Male

  (c) Prefer not to say

  (d) Other (Fill in the blank)

(13) I identify as (Circle all that apply)

  (a) White

  (b) Latin@/Hispanic

  (c) African American

  (d) Asian/Asian American or Pacific Islander

  (e) Native American or Alaska Native

  (f) Other (Fill in the blank)

(14) The main language I speak at home is

Appendix B

Student Model Coding Manual

Components and Labels

- 0 Points (Insufficient)
  - ∗ No display
  - ∗ No micro:bit/gator:bit/motherboard
  - ∗ Alligator clips going nowhere
- 1 Point (Standard)
  - ∗ Includes labels or clearly draws OR accurately describes ALL of the following
    - – micro:bit or gator:bit (similar things such as motherboard, panel board, control board)
    - – alligator clips/wiring of some sort showing connections between micro:bit/gator:bit and something (does not have to labeled as a sensor)
    - – data display of some sort
  - ∗ Plant: display doesn't need to be labelled, but lights need to be clearly drawn on the gator:bit
  - ∗ Doesn't have to the be the classroom data displays as along as a display of some sort if drawn or described
- 2 Points (Exemplary)

  - ∗ Correctly includes labels or clearly draws OR accurately describes ALL of the following
    - – micro:bit or gator:bit
    - – Sensor
    - – Illustrates OR accurately describes how the micro:bit/gator:bit is somehow connected to a sensor
    - – Data Display of some sort
  - ∗ Needs to label the LEDs either by saying they are lights/LEDs OR by telling you what they are showing OR state that they change color
  - ∗ Doesn't have to the be the classroom data displays as along as a display of some sort if drawn or described

Data Flow

- 0 Points (Insufficient)
  - ∗ There is the word data or label data included in the model and explanation but without movement implied.
  - ∗ No mention of data
- 1 Point (Standard)
  - ∗ Data is shown traveling in one direction either from the sensor (or plant) to the micro:bit or from the micro:bit to the sensor (or plant) (can be in the form of arrows, or circles, or some other shape indicating something is in the wires)
  - ∗ Data moving is mentioned (it is not sufficient to say something like the sensor collects data, the data shows hot and cold)
  - ∗ The word data does not need to present if the student somehow illustrates that something is going on in the wires

  - Students describe data moving through the system such as the wires allow the micro:bit to get the data from the sensor or the micro:bit sends the sensor data over radio to the computer graph

- 2 Points (Exemplary)
  - Shows and/or explains that data is traveling from the micro:bit to the sensor and from the sensor to the micro:bit. Anything that depicts and states data travels in both directions fits this level.
  - The word data does not need to present if the student somehow illustrates that something is going in both directions inside the wire(s) such as arrows going in both directions (into and out of the sensor)

Data Display

- 0 Points (Insufficient)
  - Draws picture of plant display but doesn't tell you what it is displaying
  - States that display is showing something other than what is listed in the next two categories
- 1 Point (Standard)
  - Plant Display: the display/lights/gator:bit/micro:bit shows how moist the soil is in the plant. It is not sufficient to say that the sensor OR model is displaying/showing information. They must provide some specific detail about display
  - Environmental Display: the display/lights/gator:bit/micro:bit shows the classroom environment using some sort of environmental words such as hot, cold, humid, loud, lots of CO2. It is not sufficient to say that the sensor OR model is displaying/showing information. They must provide some specific detail about display. To be in this

category student must show, illustrate, or describe that the display provides info about at least one named environmental characteristic

  - ∗ A more generalized description connecting the data collected to changes in the display/lights

- 2 Points (Exemplary)
  - ∗ Plant Display: the display/lights/gator:bit/micro:bit shows how moist the soil is in the plant. AND includes information that the color and number of lights indicates the moisture level (something like more lights, more moisture. Blue lights equal a lot of moisture, purple light and sound indicator no moisture). It is acceptable for an explanation to only mention the noise as an indicator of dryness. It is not sufficient to say that the sensor OR model is displaying/showing information. They must provide some specific detail about display
  - ∗ Environmental Display: the display/lights/gator:bit/micro:bit shows the classroom environment using some sort of environmental words such as hot, cold, humid, loud, lots of CO2. AND to be in this category student must show, illustrate, or describe that the display provides information about at least two specific environmental characteristic and discuss how lights are displaying the different conditions along with the letters on the micro:bit. It is not sufficient to say that the sensor OR model is displaying/showing information. They must provide some specific detail about display

Control of the System

- 0 Points (Insufficient)
  - ∗ Programming/Coding is not mentioned
  - ∗ Code/Programming is mentioned, but it is not clear how coding relates to the model
  - ∗ They need code, where they is either ambiguous or referring to something other than the micro:bit/gator:bit/motherboard

- 1 Point (Standard)
  - ∗ If they say that the micro:bit/gator:bit is coded that is sufficient (if they provide any additional CORRECT details about what the code/programming is doing they move into the exemplary category)
  - ∗ Programming/Code is mentioned as a way to control the system or make the system work
  - ∗ The key phrase to get into this category is to see in explanation that the program/code controls the system, makes the system work in some way. They don't need to specifically mention the micro:bit/gator:bit/motherboard
  - ∗ Notion of programming the system to do what you want, but little detail is provided about what you actually want it to do or how it controls the system
- 2 Points (Exemplary)
  - ∗ The big idea that moves the student from the previous category to this category is that they offer specific details about how programming is controlling the system
  - ∗ Specific mention of programming the micro:bit to tell the sensor to collect data
  - ∗ To move into this category students must show that they understand that they are
  - ∗ Programming the micro:bit to ask the sensor for information about the plant OR the classroom environment.
  - ∗ Using the code to process the sensor data to change the display