Opening the Black Box: Investigating Student Understanding of Data Displays Using Programmable Sensor Technology

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ABSTRACT

This paper describes the design and classroom implementation of a week-long unit that aims to integrate computational thinking (CT) into middle school science classes using programmable sensor technology. The goals of this sensor immersion unit are to help students understand why and how to use sensor and visualization technology as a powerful data-driven tool for scientific inquiry in ways that align with modern scientific practice. The sensor immersion unit is anchored in the investigation of classroom data where students engage with the sensor technology to ask questions about and design displays of the collected data. Students first generate questions about how data data displays work and then proceed through a set of programming exercises to help them understand how to collect and display data collected from their classrooms by building their own mini data displays. Throughout the unit students draw and update their hand drawn models representing their current understanding of how the data displays work. The sensor immersion unit was implemented by ten middle school science teachers during the 2019/2020 school year. Student drawn models of the classroom data displays from four of these teachers were analyzed to examine students' understandings in four areas: function of sensor components, process models of data flow, design of data displays, and control of the display. Students showed the best understanding when describing sensor components. Students exhibited greater confusion when describing the process of how data streams moved through displays and how programming controlled the data displays.

CCS CONCEPTS

• **Hardware** → *Sensors and actuators*; • **Social and professional topics** → **K-12 education**; **Computational thinking**; **Model curricula**.

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KEYWORDS

Computational Thinking, Middle School Science, Micro:bit, Sensors

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1 INTRODUCTION

Over the last 10 years educators and researchers have employed a wide variety of strategies to increase access to computational thinking experiences. Research has explored integrating computational thinking into the existing science and mathematics curricula [11, 19, 23, 37] with computational thinking being explicitly called out in the new United States Science Standards (Next Generation Science Standards (NGSS))[23]. Integrating computational thinking into math and science classes that are already part of the K-12 curriculum provides an opportunity to engage all students in activities involving computational thinking. This avoids the pitfall of requiring students to opt-in to such activities since many computer science and engineering classes that focus on computational thinking are electives.

Modern scientific disciplines increasingly rely on computational tools and methods when they are practiced outside of the classroom [2, 16]. As such, science classes provide a rich space for integration by employing inquiry-based instructional approaches that are designed to make classroom scientific investigations closer to the practices of real scientists [23, 29, 36].

This paper describes the design and classroom implementation of a week-long unit that aims to integrate computational thinking (CT) into middle school science classes using programmable sensor technology. The goals of this sensor immersion unit are to help students understand how sensor and data display technologies can be used as powerful tools for scientific inquiry in ways that align with modern scientific practice. The unit is anchored in the investigation of classroom environmental data where students engage with and program the sensor technology to collect and design mini-displays of their data. The unit is also designed to augment other science units in the middle school curriculum by providing an initial context for students to use sensor technology as a way to examine scientific phenomena. Then, as students engage in subsequent investigations, they have a better understanding of how and why sensor technology may be a relevant scientific tool.

The sensor immersion unit was implemented by ten middle school science and STEM[1] teachers in a large, urban school district during the 2019/2020 school year. Our examination of classroom implementations was guided by the following research question:

To what extent did participating in the sensor immersion unit help students build understanding of the different aspects of the programmable sensor technology?

As our main focus was on investigating students' understanding of programmable sensor technology, we drew on an approach used in science education research that examines students' evolving models of science phenomena as measures of their thinking and learning [31, 39]. As part of the unit, students drew models of classroom data displays built using the programmable sensor technology. We used these student-drawn models to gain insight into students understanding of how the different pieces of the programmable sensor technology fit together as they created their final data display.

2 RELATED WORK

Science has become a field that is increasingly utilizing computational tools and design processes [16]. As the field increases in computational complexity, there has been a push to introduce computational tools and concepts into K-12 science classrooms. This can help students consider careers as scientists [2] and help them see applications of computer science to other disciplinary areas [18, 25].

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 [4, 40, 45, 46]. Modeling provides an obvious point of entry for computational thinking integration because it builds off of 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. In addition, computational models and simulations are tools real scientists use to better understand phenomena.

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[2] and CODAP[3] 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 [14, 26] with CODAP supporting students to generate their own data from simulations [14]. These applications provide students opportunities to see beyond the few sample points they can collect by hand and forces them to think about issues associated with large real world data sets and such as errors, outliers, and other issues related to the integrity of data.

[1]STEM is a required class that covers a variety of science and engineering topics ranging from civil engineering to computer science.
[2]http://isenseproject.org
[3]https://codap.concord.org/

While computational modelling, simulations, and large scale data analysis provide many opportunities for integration, there are additional avenues of integration to explore. Programmable sensor technologies are becoming increasingly accessible and affordable for K-12 classrooms [1] and provide students an opportunity to collect their own large data sets and streams and to automate experimental data collection.

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 [24, 33] and art [13], investigations of phenomena that are otherwise difficult or impossible to observe [28], or come from abstract scientific theories [4]. Utilizing data streams collected by students allows them to interact with "big data" like scientists conducting their own experiments.

In collecting their own data, students are also provided with an opportunity to ground scientific investigations in their own schools and local communities. This provides a potential way to engage underrepresented groups [1, 20, 34, 44]. For example, students can explore the questions *why here?* and *so what?* to provide local context for the phenomenon they are learning about [5].

3 SENSOR IMMERSION UNIT

This unit is designed as part of a larger design project organized as a Research-Practice Partnership [8, 10, 30] between A Large Suburban University and A Large Urban School District. In Research-Practice Partnerships, researchers collaborate with practitioners to improve educational practice by solving common problems of practice [10]. This partnership is focused on researchers and middle school science and STEM teachers collaboratively designing (co-designing) [15, 32, 41] science units that integrate computational thinking into their classrooms through the use of programmable sensor technology.

This project began in the Fall of 2017 and research is conducted over year-long design cycles. One main finding from the first two design cycles is that students struggle to understand how the programmable sensor technology could be used to support their scientific inquiry. To address this issue, we co-designed a sensor immersion unit to introduce the students to the programmable sensor technology. The goal of this sensor immersion unit is to help students see the programmable sensor technology as a relevant tool for their investigations.

This section describes the programmable sensor technology used by the students and the design process that led to the sensor immersion unit that teachers implemented during the Fall of 2019. In this third design cycle, ten teachers participated: four teachers who participated in the previous two design cycles, and six who were new to the project.

3.1 Sensor Technology

This project utilizes a set of programmable sensor technology that is low cost and designed for use in the K-12 classroom. The micro:bit is a small microcontroller designed for use in education and capable of being programmed using both block and text based programming languages. The micro:bit comes with four on-board sensors: light, temperature, magnetometer, and accelerometer. For this project,

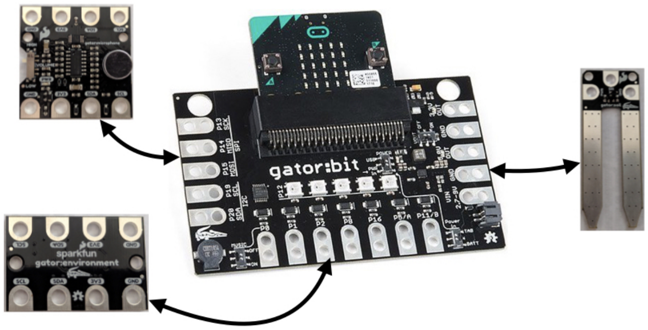

Figure 1: The programmable sensor technology for the sensor immersion unit features the micro:bit, gator:bit, and alligator clippable sensors. The sound sensor is in the top left, the environmental sensor is on the bottom left, and the soil moisture sensor is on the right.

students utilize the online, block-based programming environment, MakeCode[4].

The micro:bit is augmented by the gator:bit which makes the pins on the micro:bit, including the I2C bus, easily accessible to alligator clippable sensors, see Figure 1. These sensors include an environmental sensor that measures temperature, humidity, carbon dioxide, 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 multiple sensors to be used at one time. To support long term data collection, a real time clock and SD card data logger can also be added. Finally, the gator:bit has a built-in speaker and a neopixel array to support simple data displays.

To control the alligator clippable sensors, the micro:bit is programmed using MakeCode through the use of custom blocks for the different sensors, see Figure 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. In addition, since these blocks are available to add to any MakeCode project, no special software or local versions of MakeCode needs to be installed, which greatly increases usability especially in low-resourced school environments.

3.2 Design of the Sensor Immersion Unit

This project utilizes an instructional design approach increasingly used in science education, referred to as storylines [35, 38, 42]. This approach is used to design coherent, inquiry driven lessons that align to the practices of real scientists [36]. Storylines are anchored around a particular scientific phenomenon and the lessons are based on "driving" questions that students generate about that phenomenon. Storylines are created before individual instructional lessons to serve as an overall unit guide to generate a coherent lesson set that promotes incremental knowledge building [36].

[4]Makecode is a programming environment developed by Microsoft to support programming the micro:bit along with several other physical computing devices, https://www.makecode.com.

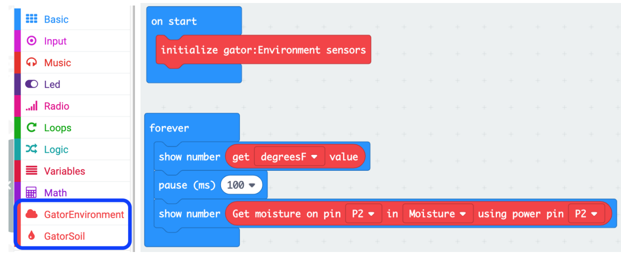

Figure 2: MakeCode, a programming environment used to program the micro:bit. The sensor specific blocks are added to the block menu and the program displayed shows the values for temperature and soil moisture.

The storyline for the sensor immersion unit was co-designed with the ten participating teacher over four day-long workshops in the Summer of 2019. Before the first summer design workshop, the research team chose the driving question, *How can sensors help us understand and communicate information about the world around us?*, anchored in the exploration of two classroom data displays built by the research team to situate the use of sensors in the classroom. One data display illustrated environmental conditions such as temperature, noise level, humidity, and carbon dioxide level in the classroom, see Figure 3, and the other data display monitored the soil moisture in a plant, see Figure 4. These displays were built using the same tools available to the students and were designed specifically so as to not hide the technology, by leaving the wires, sensors, and micro:bit/gator:bit clearly visible to the students.

During the workshop, the teachers generated a set of questions around the classroom data displays. Teachers put on their middle school "student hat" (i.e., acted like a middle school student) and interacted with the data displays by observing the different colored lights and sounds, touching the environmental sensor, removing the soil moisture sensor, etc. After this period of interaction, they wrote down each question they had about the classroom data displays on sticky notes. They shared their questions and developed categories to group similar questions together. Categories included **basic functionality** with questions such as *What are all the different pieces?*, **communication** with questions such as *What are the wires for?* and *How do the lights know the soil moisture in the plant?*, and **control** with questions such as *How can I control the lights?* and *Why do the lights change colors?*. This set of questions closely aligned with the capabilities of the programmable sensor technology.

Once a set questions have been defined, the next step in designing a storyline is determining the order in which to tackle the questions followed by creating a description of what students learn from answering each category of questions. Back, in their "student hats", the teachers determined that they wanted to investigate **basic functionality** followed by **communication** and culminating with **control**.

To explore what students would learn by investigating each question, teachers engaged in a set of potential classroom activities in their "student hats" and then wrote an explanation from the student perspective about what they learned. After generating these explanations, teachers put on their "teacher hat" to debrief the "student

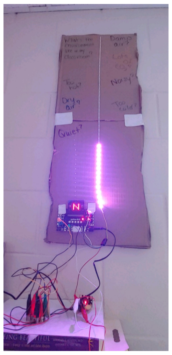

Figure 3: The classroom environment data display uses the environmental and sound sensors. The micro:bit was programmed to communicate information about four environmental conditions (temperature, humidity, carbon dioxide level, and noise level) using a strip of 30 LEDs and the 25 LED array on the micro:bit. The LEDs on the micro:bit display the variable being measured by showing a letter (e.g., T for temperature) followed by the actual value recorded by the sensor. Each environmental condition has its own color associated with it (e.g., blue for humidity) and the strip of 30 LEDs lights up in that color such that as the value of the environmental condition increases more LEDs are lit to indicate this increase. Additionally, if a predetermined threshold is reached, such as when the noise in the classroom reaches a certain level, the LED strip blinks.

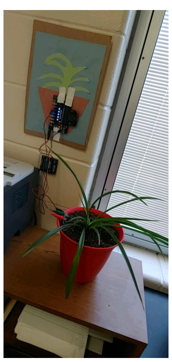

Figure 4: The plant display represents the moisture level in the spider plant's soil. The plant data display was programmed to use the 5 Neopixel LEDs on the gator:bit to indicate the moisture level in the plant with all five LEDs meaning that soil was extremely moist and one LED meaning that the soil was very dry. When only one LED was illuminated, the speaker on the gator:bit played a "sad" noise.

hat" activities and discussed what additional materials and scaffolds were necessary to support their classroom implementations. Engaging in "student hat"/"teacher hat" activities has been shown as an effective from of professional development [12, 21], especially when introducing teachers to unfamiliar computing concepts [17] and in supporting the co-design of science curriculum [6, 7]. In our work, this process led to the creation of the storyline and lessons for the sensor immersion unit, see Figure 5.

Part of each lesson revolved around students creating and updating models that they drew of the classroom data displays. Students extended and revised this model throughout the unit as they gathered more information through each investigation. As students created their models, they were reminded of work from previous units that good scientific models include components, interactions, and mechanisms [31]. *Components* represent the pieces of the system, *Interactions* represent how the pieces of the system work and communicate with one another, and *Mechanisms* represent how the entire system works. Students were able to choose between drawing a model of the plant and soil moisture sensor, the classroom environmental data display, or a more generalized description of how programmable sensor technology collects and displays information. The goal of having the students draw a model of the classroom data display is to help them internalize the functionality of how the different pieces of the system work together and how to control them. Using physical data displays provided an opportunity for the students to engage with the programmable sensor technology in an exploratory manner.

These drawn models serve both as a way for students to build their knowledge about the programmable sensor technology [22, 39] and as a window into their understanding of how the data display works [31]. Asking students to incrementally hand draw models has been a successful aspect of earlier units created as part of this project.

As described above, a typical storyline begins with a natural scientific phenomenon in which students work towards answering their questions about these phenomena [35, 38, 42]. However, in the sensor immersion storyline, the phenomenon consists of a human-made system and represents a process where students work backwards from an artifact to figure out how it was constructed. We experimented with this modification to the storyline design to see if it would help students deeply engage with the programmable sensor technology and generate questions specifically about the programmable sensor technology in relation to their classroom environment. While using a human-made phenomenon may deviate slightly from the vision of what storylines should look like in science education [35, 42], it does explicitly support place-based inquiry around the use of programmable sensor technology to measure and communicate information about the world, a critical goal of the project.

3.3 Summary of the Sensor Immersion Unit

The five days of the sensor immersion unit engage the students in trying to figure out how the classroom data displays work and how to control them. Each lesson begins with its own question based on the initial driving questions generated by the students, and builds on the previous lesson, culminating in a discussion about how the programmable sensor technology could be useful in other scientific investigations.

Day 1: How can sensors and data displays help us understand our environment through different ways of displaying information? Ideally, the classroom data displays are running

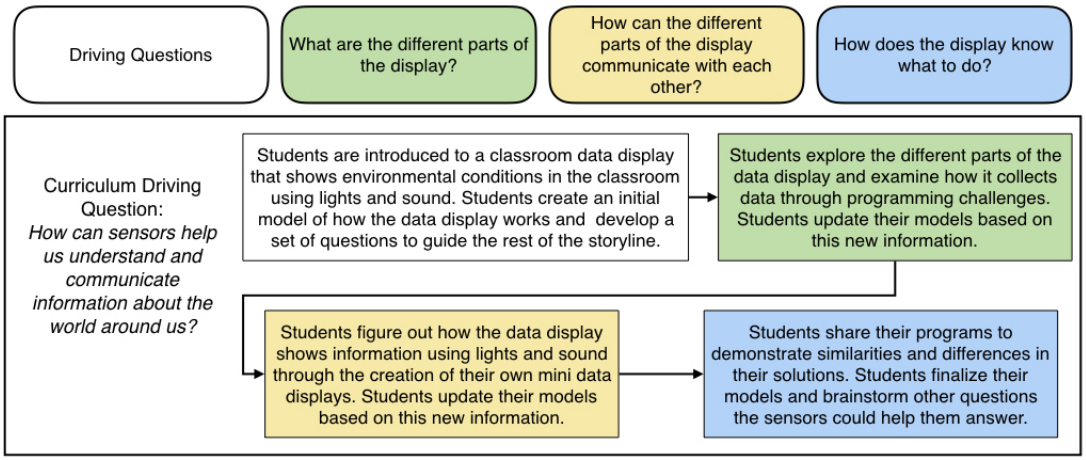

Figure 5: A summary of the sensor immersion unit

since the start of the school year in each teacher's classroom. Students do not yet know what is going on with these displays in their classrooms. 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 displays and determine which group of questions to answer first. The goal is for the students to first figure out the parts of the display, with the teacher guiding them in this direction if necessary.

Day 2: What are the parts of the data displays and how can we use the programmable sensor technology to collect data? The teacher explains the different parts of the classroom data displays 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 collects 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. The classroom data displays utilize three sensors: sound, environmental, and soil moisture; each group of students picks one sensor to focus on.

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

Day 4: How are the sensors and data displays similar and different? How can the programmable sensor technology help us in our scientific investigations? Students share their findings with the entire class about the different physical quantities each sensor can measure together with their programs. The goal here is for students to recognize similar patterns in all the different programs and in 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 by drawing final models of one of the classroom data displays.

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

4 METHOD OF ANALYSIS

Several data sources are used to address the research question. The first, primary data source are the models drawn by students. Secondary data sources, used for triangulation, include teacher interviews, teacher written responses to reflection prompts, and classroom observations. Each source and its analysis are described below.

Student drawn models. Only the final models students created at the conclusion of the unit were utilized in this analysis. The final models were chosen for two reasons: 1) they provide the best insight into students' main takeaways around the classroom data displays and programmable sensor technology and 2) the majority of teachers had their students create final models. Four of the ten teachers chose to share their students' models with the research team for analysis[5]. All four teachers are science teachers and two of them had participated in this project during the previous design cycle. The four science teachers whose students provided their drawn models are described in Table 1. Disaggregating the data by teacher allowed the research team to identify potential teacher moves that influence student thinking. As the sensor immersion unit is revised, these moves can be incorporated into the revision with

[5]Sharing student artifacts is encouraged but not required by participating teachers. Three teachers completed modified versions of the sensor immersion and did not complete final models of the classroom data display. Three teachers chose not to share their students' work with the research team.

the goal of providing teachers more resources to deepen student engagement with the programmable sensor technology.

Table 1: Table outlining the teachers who selected to share their students' final drawn models with the research team. All four are science teachers. Only student models that were not blank are counted. 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. FRL stands for Free and Reduced Lunch which serves as a metric for the socioeconomic status of the students.

Teacher	Years in Project	School FRL	Total Number of Student-drawn Models
Andrew	2	91%	38
Mark	1	95%	31
Trent	3	95%	98
Tracy	2	90%	46

In the final modeling activity, students responded to prompts on a activity sheet that asked them 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 (e.g., components, interactions, and mechanisms) and another section for students to write an explanation of the model. This limited amount of scaffolding was chosen to illicit how students were thinking about the classroom data displays and the programmable sensor technology. The models represented what aspects of the technology students thought important enough to include. The goal was to see how the unit supported students' independent knowledge building rather than guide the students with prompts based on the thinking researchers and teachers desired to see.

An open coding approach [43] that focused on looking for facets of student thinking [27] present in the student models was used to analyze the concepts represented in the final models. Facets of student thinking is a strategy for examining student work that first lists all the ideas communicated by the artifact and then categorizes them into similar groups of ideas. Each idea in a category is ordered in terms of depth of knowledge communicated to develop a continuum of student thinking. The goal is not to look for correctness of the ideas but just the different ideas present in the models.

Coding the student-drawn models was a two-step process. First, our teacher partners worked with a small sample of student models to develop the initial set of ideas (or facets of students thinking). Then, the first author refined those ideas using a larger set of student models to develop a coding guide. The coding guide considered the richness of the ideas in order to develop levels of sophistication in understanding. We specifically chose to have the teachers develop the initial set of ideas because a key tenet of a Research-Practice Partnership is to include practitioners in the data analysis process where appropriate [9].

At a professional development workshop during the school year, the nine teachers present developed an initial set of categories based on six student models selected by the research team. These models showed variable sophistication in student understanding of the classroom data displays and were selected from two different classrooms. Teachers split into two groups and each group developed their own categories around the ideas presented in the student models. Each teacher viewed each model and added sticky notes to represent the ideas they saw communicated by the students 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. The structure of this activity is based on one described in the STEM Teaching Tools[6].

Group One identified 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 that data can move. Display included ideas such as lights and sound. Coding included ideas around using the computer to code.

Group Two identified five categories as well: Set Up, Data, Display, Coding, and Other. Set Up included depictions of the sensor connected to the micro:bit using wires and general descriptions of how the classroom displays were set up. 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 micro:bit needed to be coded to work. In the Other category, they included ideas that did not fit any of the previous categories such as a student's analogy to the micro:bit as the brain of the system.

After these initial categories were developed by teachers, a set of 10 student models that demonstrated a range of understanding was used to refine the categories described above into four categories: Components of the Display, Flow of Information in the Display, Description of what the Display Shows, and Control of the Display. The Components of the Display represent the different pieces that make up the display such as the micro:bit, gator:bit, sensors, alligator clips, and lights. The Flow of Information in the Display describes how data moves throughout the system between the micro:bit, sensors, and lights. For example, the micro:bit *asks* the sensor for a reading and the sensor *returns* the reading to the micro:bit. The Description of what the Display Shows highlights what information the display provides (e.g., the plant display shows the moisture level in the soil with five blue lights representing full moisture, and one purple light representing extreme dryness). The Control of the Display details how programming the micro:bit controls the entire system from data collection to data display. While not explicitly stated these categories align to the components (Components of the Display), interactions (Flow of Information in the Display and Description of what the Display Shows), and mechanisms (Control of the Display) described above as features of good scientific models.

For each category, a 3-point scale around a continuum of understanding of each category was defined (0 points - no or very limited understanding, 1 point - standard level of understanding,

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

and 2 points - exemplary level of understanding). An initial coding guide was developed with descriptions of the continuum for each category. The student models were then divided up into groups of 10, involving a mix of models with different levels of understanding and from different teachers. In order to increase inter-rater reliability, the coding guide was refined over 4 rounds of practice coding (10 models per round) with the first, second, and third author until the first author and one colleague were in agreement on at least 80% percent of the models for each category. The definition of the continuum within each category was refined during each round. A summary of the final coding guide is in Table 2. When determining the level of understanding, the focus was on the understanding they exhibited and not on any incorrect pieces of information. Uncertainty was resolved through consensus discussions among the first three authors. After a suitable level of inter-rater reliability was achieved, the first author scored all of the models.

Table 2: A summary of the categories in the coding guide.

Category	Description
Components of the Display	To receive a standard score, a student must illustrate or describe the major parts of the system: micro:bit/gator:bit, display, sensors. They do not need to explicitly draw or label the sensor. To receive an exemplary score, a student must illustrate or describe the sensor in relation to the rest of the system.
Flow of Information in the Display	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.
Description of what the Display Shows	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 of the Display	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.

Secondary data sources. To triangulate with the student model scores, semi-structured teacher interviews were conducted with each of the four teacher participants at the conclusion of the sensor immersion unit. The semi-structured interview focused on how the implementation of the sensor immersion unit went as a whole. In addition, the teachers were asked about each specific day of the sensor immersion unit, probing for students' understanding and struggles with how the data displays worked along with students' level of engagement and interest in the investigation. In addition to the interviews, teachers completed a short written reflection after each implementation. The written reflection 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, the first author was present in each of the four teacher's classrooms for the majority of the lessons acting as a participant observer. This additional data provided context for the four individual classroom implementations and insight into variation across classrooms.

5 RESULTS

The student drawn models for all four teachers were scored using the coding guide described in the previous section. There were a total of 213 models. For complete results, see Table 3. This section highlights the overall results as well as presents an examination of each teacher's implementation. Highlighting each teacher's implementation provides insight on how variation in implementation can affect student understanding.

Table 3: The frequency (and percentage) for students' model scores in each coding category from each teacher.

Teacher	Model Score	Components	Data Flow	Display	Control
Andrew	0	32 (84%)	37 (97%)	38 (100%)	34 (89%)
	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 and drawing activity proved very challenging for students with most students struggling to illustrate their understanding of key elements and functionality of the classroom data displays. Students were most successful at identifying the components of the classroom data display with 32% of them receiving a standard or exemplary score. Students struggled the most with understanding how information flowed throughout the classroom data display with only 12% of students including information flow in their models.

Andrew had his students draw three models throughout the sensor immersion unit: on the first day, third day, and final day. Andrew's class achieved the most success in the categories of labeling the components and describing the control of the display. His students had limited to no success in describing the flow of information or the description of the display. Andrew focused most of the sensor immersion unit on programming the micro:bit and did not focus on the use of the sensors and the data display beyond the first and last lesson (a potential reason his students struggled to achieve exemplary component scores when compared to the three other teachers). When programming the micro:bit, the students got to choose what to program and 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, Andrew 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 highlight during the post implementation interview that he would devote more time to discussing student models when he implements the unit in the future.

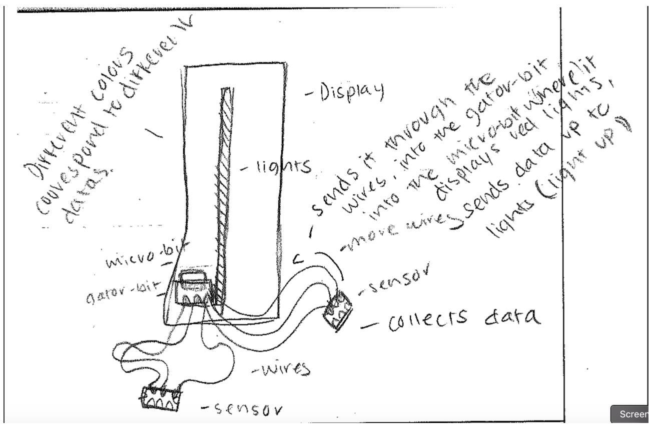

Figure 6: A student model from Mark's classroom, illustrating data moving from the sensors to the micro:bit but not from the micro:bit to the sensor.

Mark was the only teacher that had his students update their model at the end of each lesson. Mark's students performed best in the components and display categories. In particular, all students who demonstrated understanding of the components of the display exhibited exemplary understanding (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 help 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 illustrated the flow of information in the model. However no students illustrated bi-directional flow of information. The model in Figure 6 is an example of a student showing data moving from the sensor to the micro:bit to the display. However the student does not describe how the micro:bit first has to *ask* the sensor to collect data. Mark commented that in future implementations, he would spend more time focusing on having students draw models and familiarizing them with how to draw good scientific models.

Trent had his students create an initial model and a final model. Trent's students were relatively successful across all four categories with his students demonstrating the deepest understanding of control of the displays when compared to the three other teachers. In addition, his students had the second best scores in the flow of information and the description of the display. One of Trent's students

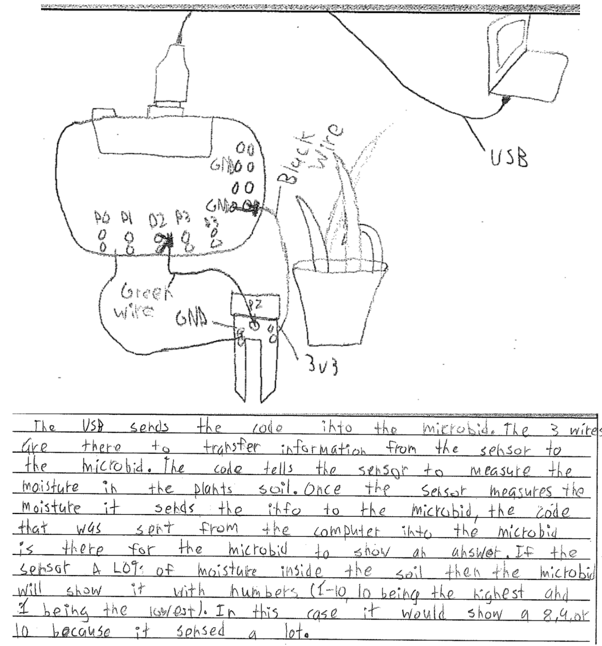

Figure 7: An exemplary student model from Trent's classroom.

was the only student to demonstrate an exemplary level of understanding in all four categories. This student's model is illustrated in Figure 7. The explanation is the most complete explanation of how information is moving through the system. Trent was also the only teacher to explicitly lead a classroom discussion around how the students completed the mini data displays for each sensor. This discussion gave students the opportunity to see the similarities and differences in their programs. Through this discussion, students came to recognize the fact that the pieces of the programs that actually collected data were similar across all sensors. In his interview, 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 students' discussion where they could readily see similarities and differences in the programs they wrote to collect data, but were less confident discussing the data displays.

Tracy had her students create an initial model and a final model. Tracy's students demonstrated in their models the greatest depth in understanding in the components of the display, flow of information, and description of the display when compared to the three other teachers. Tracy utilized the classroom displays from the beginning of the school year and students were constantly asking questions about them. She even used them to justify getting fans in her classroom when the first few weeks of school were extremely warm. Of all the teachers, Tracy utilized the classroom data displays the most outside of the sensor immersion unit.

Tracy noted some interesting trends in how her students engaged with the sensor immersion unit. She found that her traditionally lower performing students showed much more persistence around using the programmable sensor technology when compared to her traditionally higher performing students. The students that traditionally struggled were more willing to ask questions and try alternative solutions whereas her higher performing students more frequently gave up or relied on other students to do the work for them. One potential reason for this is that Tracy described her own 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 relied on asking other teachers and researchers for help.

Tracy remarked that her lower performing students were used to struggling with tasks in school. 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." Tracy stated that in the future she would modify some of the lessons in the sensor immersion unit so that students could only be successful through first overcoming failure.

6 DISCUSSION

While the overall percentage of students who demonstrated a standard or exemplary depth of understanding in the four coding categories was small, there were some general themes around students' ideas that emerged in examining students' model drawings around how the different piece of programmable sensor technology interact to create data displays. These themes will help guide the revisions to the sensor immersion unit and provide guidance to teachers who implement the unit in the future.

To what extent did participating in the sensor immersion unit help students build understanding of the different aspects of the programmable sensor technology?

The students showed the highest level of success in illustrating understanding of the components of the data display, with almost one third of the students successfully creating models that demonstrated at least a standard level of understanding. Most students included the components in their illustrations, but some students included them in their explanations. In general, students were expected students to express the most sophisticated understanding in the different components of the programmable sensor technology because the students could physically see the different components and most had experience putting together the different pieces when making their own mini data displays. However, the student drawings also suggest that students struggled to understand which part of the system was the sensor and which part is the micro:bit/gator:bit. Classroom observations revealed that this idea was sometimes inherent in the language teachers used to described the classroom data displays as well. They would refer to the micro:bit, gator:bit, and sensors generically as sensors.

Students struggled more with representing how the different components interacted with one another and how those interactions were controlled. Most students models did not illustrate any interactions (flow of information and description of display) or mechanisms (control of the system) and of those that did, most did not demonstrate exemplary levels of engagement with the ideas.

If students described the flow of information in the displays, they connected the idea that the sensor was collecting 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 such as 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.

Findings also suggest that the concept of information 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 illustrated the flow of information in their drawings most often described data going from the sensor to the micro:bit. However, the sensors have no notion of how to send data to micro:bit unless the micro:bit *asks* the sensor for that information. Students thought the sensors could control themselves. This struggle is also shared by many of the teachers. During the summer workshops, teachers created their own models of the displays and many teachers did not highlight communication from the micro:bit to the sensor.

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). However, most students did not provide details connecting the values from the sensors to change 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.

The main mechanism in how the different pieces of the programmable sensor technology work together is the idea of programming the micro:bit to control the data display. While the majority of students engaged in programming activities using the micro:bit, most did not represent that idea in their model of the classroom data display. Of the 16% that did, only a small fraction (2% of all students) provided further details about how programming the micro:bit controlled the classroom data display (e.g., the micro:bit was programmed to collect data from the soil moisture sensor and use that data to turn on a specific number of lights). This confusion would make it challenging to use the sensors in future scientific investigations without significant support from their teacher or tutorials.

Teacher variation. Overall, there was some variation across teachers in terms of the kinds of models drawn by their students, with Tracy and Trent's students exhibiting greater understanding of the data displays and programmable sensor technology as compared to Mark and Andrew's students. While all teachers were given the same curriculum, teachers were encouraged to provide their own style to the implementation as part of the co-design process. Differences in the uptake of curriculum and how teachers chose to spend time on different units can influence student learning [3].

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 a hot spell at the beginning of the school year. She also gave her students extra time to create their own mini data displays. This differentiated her from both Trent and Mark who followed the curriculum more closely and did not provide extra time for their students to spend tinkering with the mini data displays. One of Trent's goals for the year was for the students to be motivated to independently engage with the programmable sensor technology during their scientific inquiry, something that his students had struggled with during the previous year. Trent's previous experience led him to spend more class time than Mark (who was new to the project) discussing the block programs the students created and how the programmable sensor technology could be used in other scientific investigations. Andrew did not focus as much on the classroom data displays and instead spent the majority of the time introducing his students to programming. The focus on programming decreased the amount of time students spent interacting with the sensors.

General discussion. The sensor immersion unit is a very condensed unit with a lot of 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' own lack of knowledge about how the classroom data displays worked. Teachers missed highlighting some of the key concepts represented in the student models such as the flow of information.

One suggested revision to address this issue is to have the teachers construct their own data displays to help anchor the sensor immersion unit. During workshops, teachers would engage in "student hat" activities around constructing their own data displays as well as drawing models of the display they created. Reflecting on this process in their "teacher hat" presents an opportunity for the teachers to build knowledge around the functionality of the display. Additionally, they can develop strategies to support their students to not only be motivated to use the programmable sensor technology, but also have the skills to set up and use the technology in their scientific inquiry.

The creation and revision of the hand drawn models provided students an opportunity to reflect on what they learned from engaging in the programming activities. Several teachers remarked that in future iterations of the sensor immersion unit, they would devote more time in each class period to the student models.

While we have presented several areas for improvement during future iterations of the sensor immersion unit, the implementation of unit did have several successes. The unit was centered on the classroom environment that students could easily explore. Students were able to generate many questions about the classroom data displays with all the programmable sensor technology visible to them. Most students designed and programmed their own mini data display using data collected from one of the sensors. Lastly, while we have not yet conducted analyses of the usage of programmable sensor technology in subsequent units, teachers have shared anecdotal evidence that students are recognizing and using the sensor technology as a tool for scientific inquiry.

7 CONCLUSION

This paper presented a novel way of introducing students to programmable sensor technology as tools to support their scientific inquiry through the automated collection and display of classroom environmental data. In addition, this paper outlines a research strategy of using students' hand drawn models to gain insights into their understanding of how programmable sensor technology works. While students showed relatively limited and varied understanding of the programmable sensor technology, their models provide a basis on which to build revisions to the sensor immersion unit by focusing more on how the different pieces of the display fit and function together.

Specifically, students need to gain an understanding of what the different pieces of the display are, how they are controlled through programming, and how information flows through the display. Instead of merely telling students this information, the goal is to revise the sensor immersion unit so that the students come to these understandings on their own through deeper explorations of the displays and discussion with both classmates and their teacher about how the entire display functions.

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