Teaching Science with Technology: Scientific and Engineering Practices of Middle School Science Teachers Engaged in a Robot-Integrated Professional Development Program (Fundamental)

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Teaching Science with Technology: Science and Engineering Practices of Middle School Science Teachers Engaged in a Professional Development for Robotics Integration into Classroom (Fundamental)

1. Introduction

What teachers do *vis-à-vis* their instructional practices and how they interact with students are paramount for increasing engagement in a classroom and enhancing academic achievement. Despite the sustained efforts and calls to reform teaching practices, national survey data show that U.S. science teachers are still using traditional and typical teaching practices. The 2012 national survey of Science and Mathematics Education (3,701 science teachers from 1,403 schools from grades 1—12) showed that roughly 96% of the middle school teachers explained science ideas to the entire class and 92% of them had the entire class engage in discussions [1]. Small group work in science classrooms was implemented by approximately 79% of middle school science teachers [1]. The majority of instructional practices in science classrooms are implemented in the traditional manner and thus there is still a large demand to integrate the reform-oriented teaching practices into science classrooms [1]. Understandably, in recent years, a variety of U.S. standard documents has recognized the need and importance for a reform-oriented teaching approach. For example, the Next Generation Science Standards (NGSS) [2] have emphasized the science and engineering practices for creating inquiry-based learning environments wherein students engage as active participants and develop cognitive skills and processes. Guiding and helping teachers as they begin to consider implementing desired teaching practices can further the aim of students gaining deep understanding and meaningful learning experiences of the given content and context.

Research on reform-oriented teaching practices has recently gained attention from education researchers and teacher educators as an effective lever to improve student engagement and academic achievement. The NGSS [2] and the Framework for K-12 Science Education (the Framework) [3] reimagine science education wherein student learning and performance combine active engagement in authentic practices of science and engineering with applications of crosscutting concepts to elucidate core disciplinary ideas. The aforementioned national standard documents proposed the following eight integral science and engineering practices (SEPs), which represents a significant departure in reformulating the various levels of U.S. educational system: (1) ask questions and define problems; (2) develop and use models; (3) plan and carry out investigations; (4) analyze and interpret data; (5) use mathematics and computational thinking; (6) construct explanations and design solutions; (7) engage in argument from evidence; and (8) obtain, evaluate, and communicate information. To ensure that students can meet the new standards, it is of paramount importance that their teachers leverage the SEPs in instructional planning and implementation. Use of technology in the context of science teaching and learning can also help teachers perform inquiry-based teaching so that students can have meaningful learning experiences

[4—6]. In a recent effort, we developed and conducted professional development (PD) workshops focused on using robotics technology to provide a supportive opportunity and environment to teachers to experience the use of robotics in classroom teaching and to lower their perceived apprehension about its classroom integration. The projected outcome through the PD is to improve the teachers' curriculum knowledge and standard aligned instructional practices with the ultimate goal of improving student achievement. This paper provides a picture of how NGSS-based instructional practices are embodied and enacted in middle school science classrooms after the PD program of three-week duration.

2. Theoretical Framework

2.1. NGSS science and engineering practices (SEPs)

The NRC Framework [3], which forms the basis for the NGSS [2], expressed a vision in science learning through the three interrelated dimensions: disciplinary core ideas (DCIs), crosscutting concepts (CCCs), and science and engineering practices (SEPs). One of the key aspects of the expressed vision is for students to learn DCIs in the context of SEPs. The SEPs are multifaceted and encompass the practices used by professional scientists and engineers as they design, test, and build theories about the natural and/or designed world. The importance of these practices is stated in the Framework [3] as follows.

> *Standards and performance expectations that are aligned to the framework must take into account that students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. At the same time, they cannot learn or show competence in practices except in the context of specific content.* (p. 218)

In addition to "knowing" the science concepts, students are expected to use their understanding to investigate the natural world through the practices of scientific inquiry, or solve meaningful problems through the practices of engineering design.

In keeping with the NGSS-based SEPs [2], teachers should implement the following instructional behaviors.

1. Asking questions and defining problems: As students investigate and explain natural phenomenon, engage them in posing questions and seeking additional information about the functioning of the natural world. Moreover, engage students in formulating problems that can be addressed by designing new or improved tools.
2. Developing and using models: Have students construct, utilize, and iteratively refine models for representing, describing, validating, and predicting natural phenomena.

Moreover, engage them in employing models to produce data to help analyze or design engineering systems. Expose students to tools for modeling, such as, diagrams, drawings, analogies, storyboards, computer simulations, etc.

3. Planning and carrying out investigations: Have students design and perform investigative activities that can produce answers to questions or validate hypotheses. Use data collection as a systematic process to obtain evidence for answering scientific questions. Setting up and performing an experimental design to test hypothesis is an integral component of this practice.
4. Analyzing and interpreting data: As students conduct scientific investigations or engineering design, have them perform generation and collection of data, its analysis, and interpretation to draw meaning, scientific conclusion, or support design decisions. Graphical displays including tables, maps, charts, and statistical analysis ought to be used by students to uncover patterns indicating relationships in data.
5. Using mathematics and computational thinking: Have students apply mathematical concepts to analyze results of scientific investigations, formulate and address engineering problems, and support their explanations. Using mathematical representations, students can describe and support scientific conclusions and design solutions. Finally, allow students to use digital tools (e.g., computers, robots) to analyze data sets for patterns and trends.
6. Constructing explanations and designing solutions: Engage students in creating explanations of data, observations, and predictions to support their hypotheses and conclusions. Moreover, have students examine their design solutions *vis-à-vis* criteria and constraints, assess design trade-offs, and perform design refinement.
7. Engaging in argument from evidence: Have students engage with one-another in exchange of their explanations of a scientific phenomenon or design solution while gracefully accepting peer feedback. Such an interaction, where arguments are based on evidence and strengthened through peer feedback, can enable students to identify superior explanations and designs for the underlying problem.
8. Obtaining, evaluating, and communicating information: All students should have the opportunity to engage in this critical activity of science and engineering. They should have varied opportunities to perform it multiple ways, including, visualizations, orally, and in writing.

2.2. *Review on effective teaching practices in science education*

Many scholars have identified and decomposed effective teaching practices; thus, the number of science teaching practices available to teachers is vast. This subsection, however, reviews core science teaching practices that take into account the most recent goals identified by the NGSS. Teaching practices in science classrooms have long been linked to “inquiry” teaching [7]. The perspective that inquiry-based teaching is effective in improving science learning was advanced by the original National Science Education Standards (NSES) [8]. According to the NSES:

> *Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.* (p. 23)

The Framework [3] further clarifies that the goal of teaching science is to support all students to develop a meaningful understanding of the content and process of science. Educators need to engage students in developing questions that can lead them to deeper understanding based on their prior knowledge; use their own observations and investigations to build key concepts and relevant processes, obtain feedback, and then apply them in diverse contexts; manipulate and regulate their learning by investigating and evaluating their ideas with feedback from teacher and peers; and participate productively in scientific practices and classroom discourse by articulating their ideas.

Ref. [6] emphasized engaging students in the practices of inquiry such as "designing investigations," "collecting evidence," and "analyzing data" and it encouraged the scientific discourse in developing explanations of scientific ideas and prediction of scientific models using evidence. These are consistent with the NGSS-based SEPs including "analyzing and interpreting data" and "constructing explanations and designing solutions." Ref. [6] also valued "hands-on activities" using "scientific resources" such as lab materials and technology as an effective science teaching practice. Ref. [9] proposed ten elements of science teaching practices based on the vision of inquiry-oriented instruction in the NSES [8] and the Mosaic-II project [10]. Table 1 shows the detailed descriptions of each component, adapted from [9].

Ref. [11] proposed four core instructional practices, which include: (1) constructing big idea; (2) eliciting students' ideas to adapt instruction; (3) helping students make sense of material activity; and (4) pressing students for evidence-based explanations. Drawing out students' ideas and scientific explanations is consistent with the NGSS SEPs. The authors in [8] noted that these core practices provide students opportunities to construct explanations supported by evidence rather than reproduce the existing body of knowledge. Ref. [12] identified the following set of nine core science teaching practices by using a group of experts with the Delphi approach. (1) Engaging students in investigations—teachers provide opportunities for students to investigate phenomena and engage in scientific practices, such as, asking questions, collecting data, and arguing from evidence. The Framework [3] has similar practices about "asking questions" and "engaging in argument from evidence," highlighting that students at any grade level should be able to ask questions, originating from one's own curiosity about the world, for further analysis and interpretation. Moreover, students should engage in the process of argumentation to advance an explanation of a phenomenon and defend their ideas. (2) Facilitating classroom discourse—teachers facilitate a small group and whole class discussion where students share their explanations and arguments. (3) Eliciting, assessing, and using student thinking about science—teachers effectively probe student thinking through a variety of assessment practices. (4) Providing feedback to students—teachers provide students feedback and opportunities for peer and self-evaluation. (5) Constructing and interpreting models—teachers help students develop explanations of scientific phenomena by using appropriate models. The Framework [3] has similar arguments that students are expected to construct models to aid in the development of explanations or to make predictions about a system under study. (6) Connecting science to its applications—teachers connect core ideas, crosscutting concepts, and practices with applications relevant to students' everyday experiences. (7) Linking science concepts to phenomena—teachers engage students in a scientific study of real-world phenomena through hands-on, laboratory activities to develop a deep understanding of the material world. (8) Focusing on core science ideas, crosscutting concepts, and practices—teachers' lessons integrate the core science or engineering ideas, SEPs, and concepts within and across disciplines, which is consistent with the interdisciplinary nature of science represented through the concept of "crosscutting ideas" in the NGSS [2] and Framework [3]. (9) Building classroom community—teachers nurture a collaborative learning community in which students feel encouraged to voice their ideas and seek clarifications.

Table 1: Ten science teaching practices ([9], pp. 7-8).

Reform-oriented science teaching practice	Description
1. Grouping	Plan lessons wherein students collaborate in groups to perform scientific tasks for achieving the lesson's scientific goals.
2. Structure of lessons	Design and organize lessons with conceptual coherence such that tasks are scientifically related and have a logical progression.
3. Use of scientific resources	Use a diverse array of scientific resources, including laboratory equipment, scientific tools, and information and computing technologies (ICT).
4. Hands-on	Engage students in scientific tasks wherein scientific phenomena is explored through physical interaction with scientific artifacts, such as materials, equipment, etc.
5. Inquiry	Engage students in science lessons wherein they ask questions; formulate investigations; gather, analyze, and interpret evidence; and answer questions.
6. Cognitive depth	Design and enact lessons demonstrating that specific instances generalize to larger concepts and that science concepts are interconnected, thus revealing the core ideas of a discipline.
7. Scientific discourse community	Promote a classroom environment that is conducive to oral and written expression of scientific thinking by all participants.
8. Explanation/justification	Teacher expectation and students' active oral and written contributions to explanations and justifications *vis-à-vis* assigned science activities.
9. Assessment	Use of formal and informal assessment of student understanding of core science concepts and feedback to students and teachers for learning and instructional decision-making.
10. Connections/applications	Plan and undertake lessons and activities that connect science to students' lived experiences, apply to real-world contexts, and explicate the interplay between science and society.

Ref. [13] reviewed the empirical literature and indicated three effective teaching behaviors: modeling, opportunities to respond (OTR), and feedback. From an instructional perspective, modeling can be described as a process that makes an abstract concept accessible through demonstration, which could reduce students' confusion and enhance understanding [14]. Examples of modeling include the science teacher demonstrating visual representations such as computer simulation, animation, etc., physical artifacts, or analogies. Research demonstrates that modeling is a powerful way to improve mindful learning and application of concepts. The second behavior, i.e., OTR, is defined as actively eliciting student response on a question, prompt, or task presented by a teacher. Prior studies have confirmed the benefit of instructional environments wherein students have frequent opportunities to engage with the teacher during instruction and receive immediate feedback teacher [13, 15, 16].

This paper addresses the following research questions. R.Q.1: How did the teachers integrate the SEPs in classrooms as they enacted robotics-integrated science lessons? R.Q.2: What limitations in teacher or student understandings were observed, or reported by teachers, that may be potential barriers to teachers incorporating the SEPs in their classrooms when implementing robotics-based lessons? By finding answers to these questions, we can understand how teachers who previously engaged in the robotics-integrated PD employed desirable teaching practices. This study offers insights for teachers, educators, instructional coaches, PD leaders, and researchers as the field begins full implementation of the NGSS.

3. Methods

3.1. PD context

Forty states in the US have education standards influenced by the Framework and/or the NGSS. In this backdrop, during the 2017 summer, over 20 participant teachers were enrolled in a three-week PD program at the NYU Tandon School of Engineering. The PD was designed to facilitate the integration of the LEGO EV3 robotics kits into existing middle school math and science curricula, emphasizing student-centered pedagogy. The PD offered ten sample lessons (e.g., energy, center of mass, number line, etc.) incorporating hands-on activities using the robotics kit. For each lesson, the alignment with standards, *viz*., the NGSS and Common Core State Standards for Mathematics (CCSSM), was illustrated and teachers were engaged in performing the lessons, discussing the lessons' appropriateness, and recommending extensions. The teachers also designed their own lessons embedded with robotics activities during the last week of the PD and shared their work with peers, providing each other with useful ideas about how to incorporate new lessons into the actual classroom. The selected lessons by the teachers were implemented in their classrooms in the following school year.

3.2. Participants

Our research team observed all teachers' lessons who participated in the PD, however, for the present paper, three science teachers from inner city public schools were selected for the case study. To maintain confidentiality, all names used herein are pseudonyms. All teachers were middle school science teachers. Rachel is an experienced teacher who has taught middle school students for 13 years. She earned master's degrees in science and in education. She is currently teaching 7th and 8th grades science and STEM. She lacked prior experience or knowledge of robotics but is familiar with the NGSS teaching practices and had applied them to her lessons for three years prior to attending the PD. Jane is also an experienced middle school teacher who has spent 11 years teaching. She earned a bachelor's degree in biology and is teaching 6th and 7th grades general science. She did not have any prior experiences with the use of robotics but had implemented NGSS-recommended teaching practices because the science curriculum in her school district was expected to change with greater emphasis on NGSS and the school's science department encouraged reform-oriented teaching practices in science classrooms. John is a 6th-8th grades teacher with seven years of teaching experience. He has a bachelor's degree in international business and a master's degree in education. He uses technology tools such as computers and tablets but has not previously used any robotics related equipment in his teaching. He had neither used nor considered any of the NGSS recommendations prior to participating in the PD. Table 2 summarizes background information of the teacher participants.

Table 2: Background information of teacher participants.

Pseudonym	Rachel	Jane	John
Gender	Female	Female	Male
Level of education	MS in Science, MS in Education	B.S. in Biology	MEd, BS in International business
Teaching subject	7th and 8th grade science, STEM	6th and 7th grade general science	6-8 math and science
Teaching years	13	11	7

3.3. Lesson context

During the design phase of the PD, the teachers spent some time developing parts of their lesson units working in pairs. They were then given opportunities to share their ideas with peers during the PD. During the lesson sharing sessions, they received feedback and suggestions that could be used to help them make changes or further develop their units.

Rachel designed a lesson unit on cell division and implemented it across two class periods (45 minutes per period). The curriculum was based on the NGSS standard HS-LS1.B (Growth and Development of Organisms) with additional resources created by her. The designed instruction aims to support the students' understanding of the mechanism of the cell cycle, including the need for DNA replication during the cell cycle and the duration of the phases of each cycle, and how does cancer cells' cycle function. Rachel provided the students with necessary foundational concepts for further exploration of the cell division at the beginning of class. During the robot activity, individual students acted out creating a pie chart to display the duration of the cell cycle phases using a robot. Rachel demonstrated to the students the use of the masking tape with the robot and guided students in drawing the pie chart finding the angle measurement for each phase. Rachel led students in a discussion about the importance of checkpoints in the cell cycle.

Jane developed and implemented a lesson plan on the center of mass to teach an object's equilibrium point. Her instruction was audio-recorded during one class period (45 minutes). This lesson is aligned with the NGSS standard HS-PS2.A (Forces and Motion) wherein the performance expectation is to explore the concepts of center of mass and balance of forces on objects. Thus, through this lesson, students can develop a model for an object's motion as the translation of its center of mass combined with the rotation about the center of mass. The specific purpose of her lesson is for students to learn how an object can be balanced on a ramp and how this balance can affect how far the object goes. In other words, the hypothesis of the activity is to find a position that prevents tipping over of a cargo (a robot with a brick represents the cargo) when the cargo drives on the ramp. Jane had the students select one of the three positions of the brick on the robot: on the front of the robot, the middle of the robot, or the back of the robot and she assigned the students to find the ideal position where the brick remains stable. Additionally, the students explored a hypothesis that the position of brick affects how far the robot with the brick goes.

John implemented a lesson plan aligned with the NGSS standard MS-PS3.B (Energy), with the intent for students to use the robot kit to explore energy transfer and work concepts. Throughout this lesson, the students participated in a hands-on activity where they rolled three balls with different masses down a ramp and allowed each ball to roll into and collide with the robot on the floor. The students measured the distance the robot moved upon the impact of the ball. In the activity, the students could recognize that energy can be transferred from one object (ball) to another (robot). When the energy transfer of the ball takes place, the ball does work on the robot and the motion of the robot changes. John developed a hypothesis with the purpose of developing students' understanding of the relationship between the energy transformation and work done, and coming to understand that the ball with the most potential energy moved the robot the farthest.

3.4. Data collection and coding

Our research team observed the teachers' lesson implementations and performed data collection in fall 2017 and spring 2018. One of the coauthors audiotaped each lesson unit. A recording device was positioned at the front of the classroom, mainly focusing on the teacher to record her/his instruction. While the audio recording aimed to capture as much detail as possible about the lesson proceedings, field notes were used to characterize the teachers' practices and learners' engagement. Following the classroom observation, each observed teacher participated in a post-interview whose purpose was to identify the opportunities for empowerment and potential barriers in their teaching.

3.5. Data analysis

We used qualitative methods to capture the presence of specific teaching practices in this study. The primary sources of data for this study are field notes and audio recordings. The teachers' narratives were transcribed word by word to see how the NGSS-based teaching practices are used. The audio recording data were analyzed using a deductive approach in which transcripts were repeatedly read and coded using the codebook, **S**ystematic **C**haracterization of **I**nquiry **I**nstruction in **E**arly Lear**N**ing **C**lassroom **E**nvironments (SCIIENCE), developed in [17] (see Appendix A for code descriptions). This instrument aims to capture teachers' instructional practices and behaviors aligned with the NGSS. The validity of the SCIIENCE has been documented in previous studies [18]. During the coding period, two coders individually coded the narratives and compared their coding; then they discussed any discrepancies in their codes until a consensus was reached for all codes. All 33 codes in the SCIIENCE were rated using a dichotomous (binary) scale for the presence or absence of each code. Cross-check with two experts in science and engineering education were then conducted to further confirm the trustworthiness of the results.

4. Results

4.1. Rachel's classroom

Her lesson commenced by eliciting students' prior knowledge of cell cycle, saying "what is it that you know about the cell cycle?" She wanted the students to use an activity sheet to write down what they knew about the cell cycle. Our coding and analysis reveal that, in this case, the predominant teaching practice is "open-ended question," followed by documentation and observation. Yet, about one-third of the 33 SCIIENCE codes were not observed. For example, asking children to create their own scientific models and encouraging them to recognize relationships among concepts to obtain a "big picture" view of underlying principles was not shown in Rachel's teaching. During the lesson, she asked many open-ended questions to elicit the students' thoughts and ideas, not providing pre-selected options. For example, she asked "When cells split it's called cell division, what caught your attention?" A student said, "Cells, sort of go through what is like a season." She also encouraged the students to record all information generated during the lesson and the robot activity on paper saying "please record it on the data table here." For the robot activity, she had the students set up the activity and then carefully observe how the robot had been programmed to display the length of the cell cycle.

Throughout the lesson, she used ICT. Specifically, she used a projector connected to a laptop computer (*Technology*), displaying a picture or text from the lesson as well as showing a video to help the students' understanding. For the robot activity, she had the students use their cellphones (*Technology*) to count time and masking tape (*Equipment*) to measure distance. The robot activity's goal is for the students to obtain numerical data and create a pie chart to illustrate the cell cycle's duration. Figure 1 illustrates students engaged in the cell cycle activity. Rachel helped them to focus on obtaining the data. The following dialog of Rachel illustrates this characteristic of "information gathering".

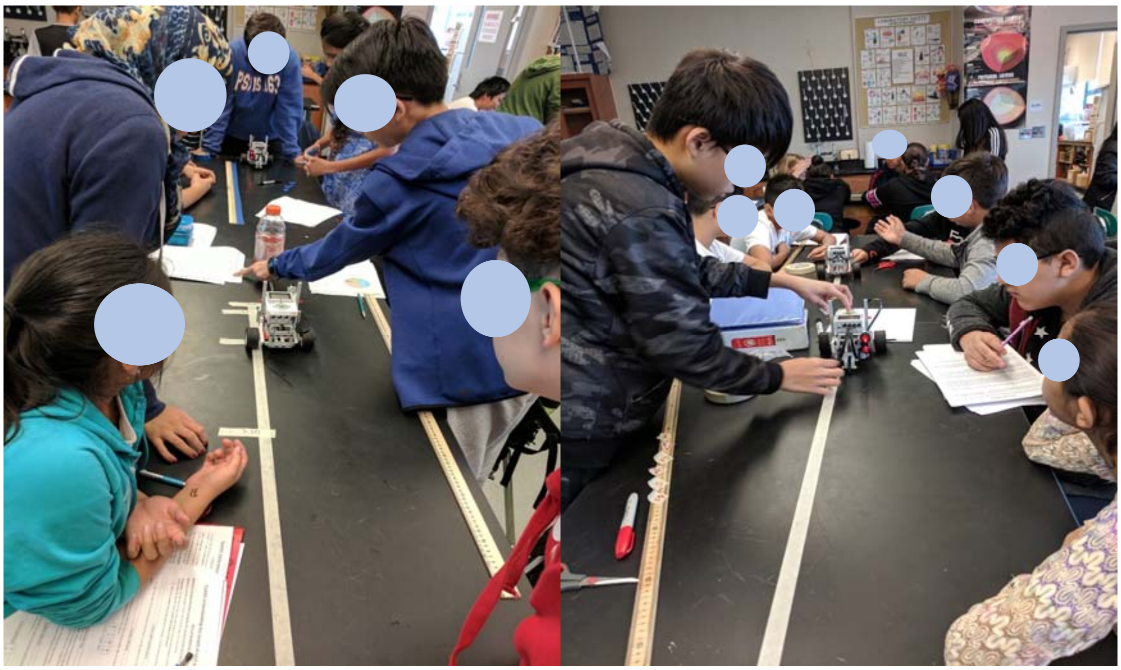

Figure 1: Cell cycle activity in Rachel's classroom.

Rachel: So this is what we are going to do, okay. You will create another pie chart. You all know how to do pie charts now. Alright, you will display the duration of the cell cycle phases using the bot. So now we are going to use a robot to do that. Everything is explained step by step by step. You're going to read each step as a group and you will perform the steps as a group. I will give you ... It's what ... I will give you up to 1:15 to collect your data.

Beyond major teaching practices, occasionally, Rachel did not immediately correct a student's misconception and instead helped the student recognize the misconception by providing content scaffolding with an everyday example. Rachel also asked a question to clarify the student's answer and elicited a satisfactory response from her students by asking sequence questions. The following exchange showed the example of "*clarification*" and "*sequence questions*".

Rachel: Alright, what is mitosis? Don, loud and clear.
Student 1: When the cells start to divide.
Rachel: When the cell starts to divide. Rena can you repeat?
Student 2: When the cells start to divide.
Rachel: Is called what?
Student 2: Mitosis.
Rachel: Mitosis. Andy, what did Rena just say. Mitosis is?
Rachel: Mitosis is.
Student 3: When cells divide.
Rachel: What does it mean by cells dividing? [*Clarification*] What are they actually doing?
Student 3: Okay, they're splitting.
Rachel: Trying to get at something else. Chris?
Student 4: They're reproducing. Multiplying.
Rachel: Very nice. Play.

After the lesson, Rachel stated that the cell cycle activity using the robots taught students an abstract science concept visually, which created a positive learning environment. Especially, students were thrilled to visualize the difference between the normal cell and abnormal cancerous cell. She highlighted the advantage of using robots this way: "Robot in itself is extremely engaging to the students. It draws their attention which otherwise is hard to attain." Additionally, she indicated that the integration of robots in the lesson has allowed engaging students in higher-order thinking skills: "… the activities were designed to engage the students into critical thinking [by] conceptualizing the underlying concepts of cell division and analyzing the gathered data." When Rachel was asked if she had any negative experiences or faced any barriers in teaching with robotics and how she resolved them, she stated that she proactively tried to foresee challenges and took necessary steps in advance to eliminate those. Following is one illustrative response:

> "I've identified tech savvy students and trained them on some of the common problems I may face. I've made them student leaders during the [robotics] activity and they monitor and fix any immediate issue. I've also organized a binder in which I've included a document on how to fix common issues facing robots. This has helped students fix issues on their own."

4.2. Jane's classroom

Jane designed the activity in which students generated hypotheses that can be tested by embedding the use of "*technology*" (robot) and several *"equipment"* (ramp, brick, ruler, tape, etc.). She emphasized the hypotheses that students should test with a scenario about a shipping company. She used limited teaching practices such as test hypothesis, observation, documentation, open-ended question. Figure 2 illustrates students engaged in the robotics activity in Jane's classroom.

Jane: Okay, I am giving out the handout right now with the instructions. So there is a scenario here about a shipping company. Yeah. And it was having trouble delivering cargo from the ship to the dock. And there are a lot of customers that have been complaining about merchandise being broken. So when the car with all of that stuff it is carrying is going up that ramp, maybe there's some kind of bump, things on the ramp, and because of that it always tips over. And because it is tipping over, it is the product inside that big box, that cargo box, is always getting broken. Okay?

So we have to figure out a way to maybe help this company solve this problem [*Test hypothesis*]. So on the picture that you see, these are the three positions that your robot will be at. You are gonna try each position I think three times. So three trials for each position and you are gonna see which one does not do so well. Okay? [*Test solution*]

Now before I give you the robots [*Technology and equipment*] you are going to make a hypothesis. Which do you think will be the best? Which position do you think would work well? [*Test hypothesis and open-ended question*]

Throughout the activity, Jane had students focus on numerical data.

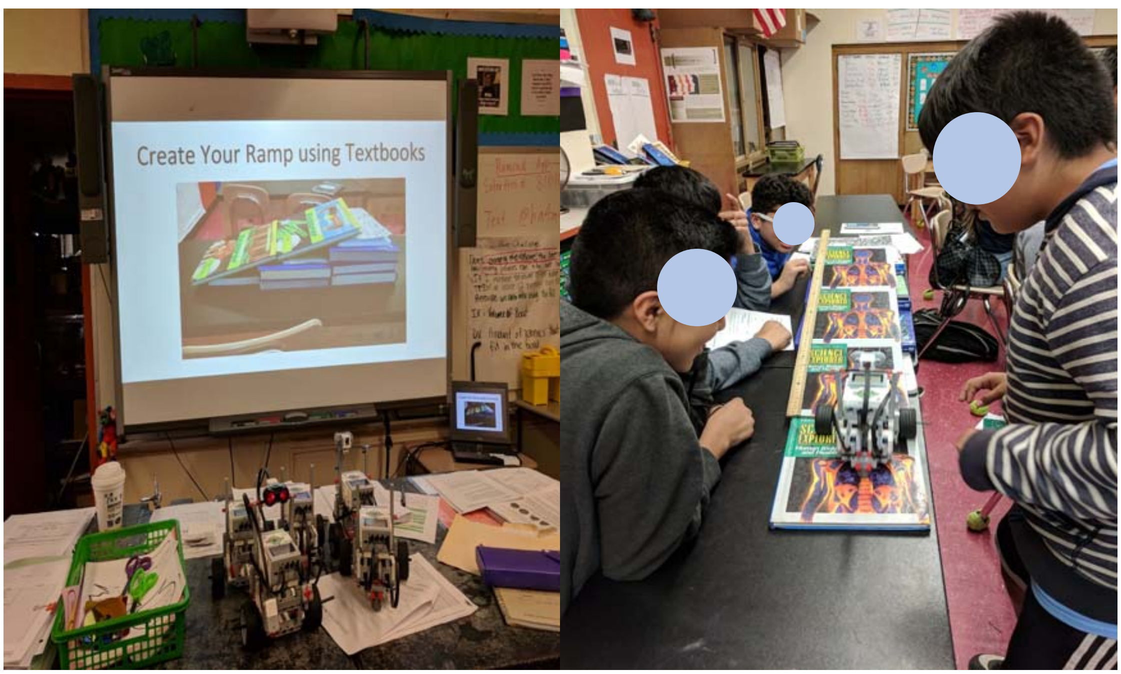

Figure 2: Center of mass activity from Jane's classroom.

Jane: I guess you need to do the up climb. You just hit start from here, the climbing up distance. Uphill, right? [*Observation*]

Student 5: Ow! [crosstalk]

Jane: Okay. So, alright now ... and to take sixty-four or? [*Numerical data*]
Student 5: Sixty-four. [*Numerical data*]
Student 5: Then the average would be thirty. [*Numerical summary*]

Jane's teaching practices did not entirely cover many portions of the NGSS science and engineering practices. However, she actively elicited hypotheses from the students which helped them to enter the actual inquiry process.

Jane: Okay, then put your check in the middle [*Documentation*]. Right, there is a little box at the corner of the picture. And once you are done with your hypothesis ... What do you think we are going to be measuring? [*Open-ended question*]
Student 6: How far it goes.
Jane: How far it goes. Good. So in the question, in the testable question, does the position of the brick affect how far it goes [*Test hypothesis*].

During her post-interview, Jane reiterated that robotics-integrated teaching empowers student learning.

> "Students are still emotionally and cognitively finding themselves in middle school. I think using robotics-integrated lessons allows students to use and apply skills that they have learned within the classroom and from their own experiences outside the classroom. For example, I have many students who struggle with math and reading, but they are able to manipulate and use the EV3 [robot] to test a scientific hypothesis. By being able to achieve a goal in an academic setting for these students can help build their confidence and resiliency. Perhaps their experience with the robots would spark intrinsic desire to learn more and explore further."

Moreover, as delineated below, she shared the challenges of using robotics for teaching indicating that the lack of time and computer resources for students limit their full participation in the activities.

> "The barriers for me are always limitation in time and computers. These barriers are usually out of the control of teachers. As part of the school's science department, collectively as a team, we can request/propose longer science class periods with each class. However, usually Math and ELA classes take up most of students' schedules. Time and class periods are usually set at the discretion of the school administration. [Moreover], in order for students to fully experience the capacity of the EV3, computers must be readily available for students to use the programming software effectively. However, computer carts at my school are not always available for science classrooms. Computer carts at my school are shared between teachers throughout the grade and priority usually goes to Math and ELA classes."

4.3. John's class

A fine-grained qualitative analysis revealed that John emphasized scientific vocabulary such as 'potential energy,' 'kinetic energy,' and 'friction' in his lesson. Sometimes, he tried to clarify the vocabulary he used by asking and explaining the definition to guide the students into having a thought process mindset of scientific inquiry. Below is an example from the lesson.

John: When it is standing still, when the object is standing still, what kind of energy is it? You used it in your answer.
Student 7: Potential. [*Voca*]
John: Potential energy, right? An object at rest has potential energy and then when I let it go, what kind of energy does it become?
Student 8: Kinetic energy? [Voca]
John: Yes, it's in your answer. When I let it go ... So, if I have two objects and one has more potential energy, when I release it, it will have more kinetic energy as well and when does kinetic energy get transferred? If the two balls pass each other like this, did any energy transfer? No. Alright?

John assisted his students through different aspects of planning and execution of activities in his lessons. For example, he encouraged students to observe their experiments and engaged them in inquiry activities to elicit their explanation through open-ended questions. Figure 3 illustrates students engaged in the energy transfer activity. The following example illustrates how the teacher involves the students into inquiries and facilitates to explain a scientific process.

John: The red ball is heavier, so you figured it was going to do what? Why did you think that? Tell me in science terms, why did you think that? [*Open-ended question & Explanation*]

At the beginning of the lesson, John led his students to make observations of an experiment to test the hypothesis, and eventually, they were prompted to access the robot and other equipment and to obtain information by participating in an inquiry. The following is an example excerpted from the lesson implementation.

John: It is made out of plastic mostly [crosstalk]. Okay. So, first column is supposed to be the height that we drop the ball [*Equipment*] from, but I am changing it a little bit. What I am gonna do is I am gonna give you three different balls [*Equipment*], right? So, that is three different masses and you are gonna roll each one down and you are gonna see if ... you are gonna roll each one down three times and then you are going to measure the distance [*Observation, Numerical data, and Information gathering*] that the ball moved the robot [*Technology and equipment*].

As the activity progressed, John recognized potential problems which the students can easily neglect and thus he provided them with appropriate scaffolding for a solution in the activity. The following example is part of instructional guidance of "design solution" when setting up the experiment.

John: Okay, cool. But if you started this ball back here, and you left the ruler there, then the measurement is useless, right? You have to always start from the same place, drop the ball from the same place, keep the angle of the [crosstalk] this? [*Design solution*]

Student 9: Incline plane.

John: Yeah, the incline plane has to be the same. Right? All that stuff has gotta be the same otherwise your data really does not help. It is not really valuable. Alright? So, take 10 seconds with each roll and make sure you line things up correctly. [*Design solution*]

Student 10: Why is this ...

John: Say again?

Student 11: [inaudible]

John: It just needs to be touching it. Alright?

Student 12: Yes.

John: Is it good?

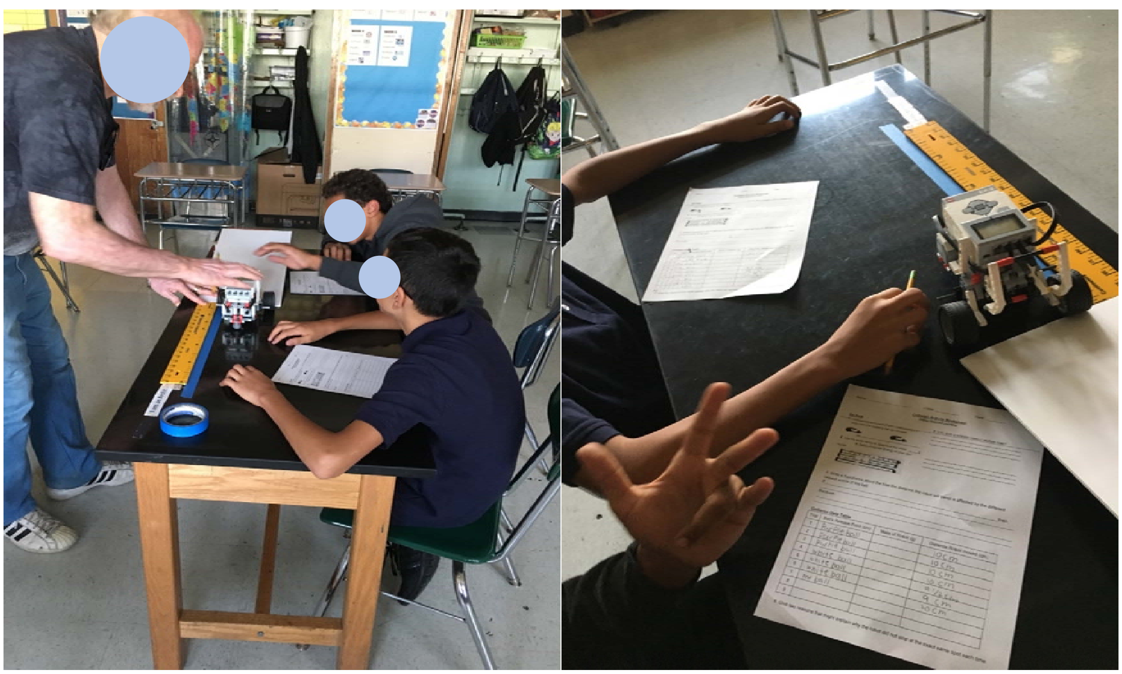

Figure 3: Energy transfer activity from John's classroom.

Similar to Rachel, John noted that the introduction of robots transformed his classroom where students are actively engaged and their academic performance improved.

> "The students actually look forward to the robotic portion of the exercise. This creates better focus in the work prior to the robots and continued focus through the inquiry-based portion. Assessments are typically better when the robots are used to reinforce the lesson. This also allows me to give the students more ownership of their learning."

John also stated that technical glitches represent a minor negative experience when using the robots.

The SCIIENCE binary scale indicates the presence or absence of eight facets of the SEPs. Table 3 shows the frequency of the presence of various teaching practices (27 out of 33 SCIIENCE codes) for the three teachers. Table 3 can be used for comparing the practices of these teachers. As seen through Table 3, the three teachers used slightly different types of teaching practices but applied almost the same number of practices (ranging from 16 to 19). Rachel and John repeatedly used teaching practices of vocabulary and open-ended questions. Moreover, John had students frequently use equipment such as balls, tapes, and meter sticks for the robot activities compared to the other two teachers.

5. Discussion and Conclusion

Even as recent years have witnessed an increased interest in raising the levels of standard-aligned teaching practices, classroom implementations lack consistency with certain practices receiving greater attention while others getting neglected. This study was designed to acquire a deeper understanding of implementation practices (R.Q.1) of teacher-developed lesson plans incorporating robotics activity and specially to uncover potential barriers (R.Q.2) to implementation of specific practices by teachers. As the benefit of introducing students to the NGSS-based SEPs through inquiry-based lessons has been increasingly recognized, it is important to capture how in-service teachers are implementing the SEPs, but research studies that directly examine the SEPs in K-12 education are rare. Furthermore, this study addresses a void in the field by linking the NGSS-based teaching practices by using a technology tool in science classrooms. The classroom observations revealed how science teachers implemented their instructional practices in lesson units with hands-on robotics activities. Moreover, this study utilized the existing SCIIENCE instrument to examine and identify NGSS-based instructional strategies and methods used for the robotics-based lessons. Our findings indicate that the students in the three teachers' classrooms learned science by active engagement in hypotheses testing by gathering empirical evidence and sharing ideas with teachers through questioning. Moreover, their use of scientific words, question generation, and documentation of results familiarized students with the scientific inquiry process. However, the three teachers' instruction did not entirely cover all the practices recommended in NGSS. For example, "modeling" and "argumentation" were not used even though these are considered effective teaching practices [13]. Using the practice of modeling can allow students to deepen their understandings of scientific concepts and the nature of science, and improve their scientific literacy [19]. Ref [20] indicated the importance of constructing models that explain scientific phenomena, showing how students' models are consistent with the evidence, and examining the limitations of their models. It is widely recognized that argumentation is a core epistemic practice of science for engaging in scientific discourse [21]. However, helping students develop models and engage in skilled discourse can be difficult for science teachers who have had few prior opportunities to learn, practice, apply, and examine such pedagogical strategies in their teaching. In summary, while some standard-aligned SEPs were readily adopted by the teachers, several others appeared to present greater difficulty for incorporation in their lesson units. The three teachers have knowledge about SEPs recommended by the NGSS but the lack of experience and training for the specific teaching practices were the main reasons that these were not consistently observed in their classrooms. A fine-tuned PD model could help equip teachers with the challenging teaching strategies and lead to changes in teachers' instructional behavior. Moreover, it is imperative to provide appropriate ongoing training and support for teachers to achieve optimal outcomes in their teaching practices.

We recognize several challenges and limitations of this study. This case study includes only three teachers, thus limiting its generalization and inferences we can make about the larger population of in-service teachers. Moreover, classroom observations before the teachers participated in the PD were not implemented due to myriad practical constraints and thus we did not have the opportunity to uncover any changes in teachers' instructional practices due to PD intervention. To address these challenges, in future research, we will aim to include more data about teaching practices of teachers prior to and after participating in the PD as well as teacher interviews to find out any changes enacted in their classroom teaching practices.

Despite the aforementioned limitations, we believe the results of this study to be a relevant addition to the much-needed research in STEM education. A key message of this study is the importance of investigating a comprehensive set of instructional practices that focus on the NGSS's SEPs and the implications for PD. Being aware of in-service teachers' current teaching practices allows teacher educators, researchers, and policymakers to make a value judgment that could help determine which aspects of practice are essential.

Future work may extend the current analyses through the inclusion of a larger sample of middle school teachers to determine what specific SEPs provide a greater contribution to increases in students' understanding and engagement level. The results identified from such a future study can inform the creation and offering of an effective PD model using technology through which teachers can gain an awareness and understanding of elements of reform-based instructional practices and mindfully make pedagogical decisions for students' meaningful engagement in science classrooms.

Table 3: Frequency of teaching practices used by the three teachers.

	Rachel	Jane	John
Practice 1: Asking Questions and Defining Problems			
Prior knowledge	5		
Elicit hypothesis	1		1
Student idea			1
Misconception	2		2
Practice 2: Developing and Using Models			
Student Model	1		
Practice 3: Planning and Carrying Out Investigations			
Information gathering	4		2
Test hypothesis		2	1
Equipment	1	2	11
Test solution		1	
Teacher demonstration		1	
Student inquiry		2	4
Observation	2	3	6
Practice 4: Analyzing and Interpreting Data			
Analysis/interpretation	5	1	
Overarching relationships		1	
Practice 5: Using Mathematics and Computational Thinking			
Numerical summary	1	1	3
Graphic summary	1		
Quantitative conclusion	1		
Practice 6: Constructing Explanations and Designing Solutions			
Explanation	2	1	6
Design solution			1
Practice 7: Engaging in Argument from Evidence			
Disagreement		3	
Practice 8: Obtaining, Evaluating, and Communicating Information			
Documentation	6	7	4
Vocabulary	10	3	10
Open-ended question	18	8	19
Sequenced question	3	1	1
Clarification	1		
Technology	5	1	5
Assessment	4	1	

Acknowledgments

This work is supported in part by the National Science Foundation grants DRK-12 DRL: 1417769, ITEST DRL: 1614085, and RET Site EEC: 1542286; and NY Space Grant Consortium grant 76156-10488. The authors thank the three middle-school teachers and their students for their participation in this study.

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Appendix A

Table A.1: Code book for science and engineering practices (adopted from [17]).

Practice 1: Asking Questions and Defining Problems Questions are the driving force of inquiry and investigation in science. Scientific questions are often inspired by curiosity about the world and natural phenomena. In engineering, questions seek to identify problems and needs within society, which lead to the designing of technological solutions. Students should be encouraged to ask questions in science that reflect their curiosity and gaps in their knowledge of the content under investigation. These questions can be used to develop inquiry investigations and guide students' thinking during their explorations.	
1.a Prior Knowledge	Teacher asks students to recall previous knowledge from outside the current classroom. Students are asked to think about their prior learning or past experiences and this knowledge is then connected to the lesson.
1.b Elicit Hypothesis	Teacher asks students to predict the outcome of a situation, either in preparation for an experiment or as part of a hypothetical discussion.
1.c Student Idea	Teacher uses student ideas or suggestions to shape an activity or discussion. When students propose an idea for an experiment that was not planned or ask an off-topic question, the teacher accommodates and incorporates the idea into the lesson.
1.d Misconception	Teacher does not immediately correct student's misconceptions or otherwise incorrect answers. Instead of emphasizing right and wrong, emphasis is placed on using inquiry or questioning to help students recognize their misconceptions on their own.
Practice 2: Developing and Using Models Scientific models are visual representations of objects or phenomena. They are often used to help visualize objects or processes that cannot otherwise be directly observed and to help explain those processes. They enable scientists and engineers to examine a system or parts of a system and to communicate their explanations of these systems to others. Students should become familiar with the function of scientific models, be able to analyze and interpret those models, and learn to construct their own models of scientific phenomena.	
2.a Student Model	Teacher asks students to create models to represent scientific concepts or processes. Models can be two-dimensional (e.g., drawings) or three-dimensional (e.g., constructed from physical materials).
2.b Model Discourse	Students are engaged in discourse about an existing model. This discourse may include interpreting the model, explaining the scientific concept demonstrated within the model, or using the model to make predictions or draw conclusions.
Practice 3: Planning and Carrying Out Investigations Scientific investigations have two primary purposes: to systematically describe the natural world and to test theories and explanations of how the world works. The first requires the use of careful observation to obtain information and often identifies questions that must be further explored. The second requires controlled experiments that seek to isolate specific variables and obtain data to support or contradict a hypothesis. In engineering, investigations are used to test and evaluate the quality of a design. Students should gain experience in carrying out scientific investigations as a means of obtaining information and answering their scientific questions. They should become familiar with the scientific processes underlying the inquiry process.	
3.a Information Gathering	Teacher designs activities in which students are focused on obtaining data for a specific purpose. The purpose could be to test a hypothesis or design or to answer a specific question.
3.b Test Hypothesis	Teacher designs activities in which previously generated hypotheses are tested. The data obtained during the investigation will be used to support or reject the hypothesis.
3.c Equipment	Teacher provides task-specific equipment or tools for students to use to aid in inquiry activities or information gathering.
3.d Test Solution	Teacher designs activities in which previously generated solutions are tested. The solutions will be evaluated for the quality of their performance.

3.e Teacher Demonstration	Teacher demonstrates an inquiry activity for students. This can either be done as a preview for students before they perform an activity themselves or the entire activity is conducted by the teacher.
3.f Student Inquiry	Students are engaged in an inquiry activity that explores a scientific concept using a hands-on approach.
3.g Observation	Teacher encourages students to closely observe an object, a phenomenon, or their surroundings. Observation can include any of the five senses. This can occur through a statement directing a student's attention or through a question that asks students to describe what they are currently observing.

Practice 4: Analyzing and Interpreting Data

In order to gain meaning from their investigations and experiments, scientists must consolidate and interpret the data they obtain. This allows scientists to identify patterns, examine potential relationships among variables, and determine whether or not the data supports a hypothesis. Engineers analyze experimental data in order to evaluate the quality of a design. Students should become familiar with the process of interpreting the results of their investigations in order to derive deeper meaning and greater understanding of the scientific concepts being examined. They should learn to make connections between multiple pieces of information and begin to understand the broader concepts and theories underlying a given topic.

4.a Analysis/Interpretation	Teacher leads students to consolidate and interpret the results of their investigations. This includes recognizing patterns, comparing and contrasting objects, and determining whether data supports a hypothesis.
4.b Overarching Relationships	Teacher encourages students to recognize relationships among concepts to obtain a ''big picture'' view of the underlying principles.
4.c Move Past Misconceptions	Teacher uses strategies to help students move past their misconceptions. Discussions or results of experiments are used to get students to recognize their mistakes and resolve them.

Practice 5: Using Mathematics and Computational Thinking

Mathematical concepts are integral to the fields of science and engineering. Scientists and engineers often collect measurements, perform statistical analyses of quantitative data, develop formulas to explain phenomena, and use those formulas to make predictions or construct designs. Students should become familiar with obtaining and analyzing numerical data and working with mathematical formulas, when applicable. Students can use numbers to identify and describe patterns and express relationships.

5.a Numerical Summary	Teacher or students obtain numerical data and consolidate, organize, and/or analyze this data. This can also include statistical analyses of the data, such as computing an average.
5.b Graphical Summary	Teacher or students create a graph of data collected for interpretation and analysis. This includes bar graphs, pie charts, scatter plots, etc.
5.c Quantitative Conclusion	Teacher guides students to draw conclusions from numerical or graphical summaries of data.

Practice 6: Constructing Explanations and Designing Solutions

Scientists develop theories to explain the functions of the natural world. These explanations are based upon numerous sets of data and are often evaluated against further data to either support the explanation or suggest the need to revise it. Engineers use this scientific knowledge to design solutions to address various problems or needs. Students should practice developing their own explanations for observed phenomena based on scientific knowledge and evidence and to identify flaws in their explanations when they are inconsistent with evidence. Students should be able to apply their knowledge to develop designs and solve potential problems.

6.a New Situation	Teacher helps students relate previously-learned concepts to new content. Students are asked to apply their knowledge from previous lessons to new situations, such as solving hypothetical problems.
6.b Explanation	Teacher asks students to generate their own explanations for observed or hypothetical phenomena. These are likely to be ''how'' or ''why'' questions that seek to obtain an explanation of a scientific process.
6.c Design Solution	Teacher provides students with a situation or problem and asks students to generate potential solutions. This could be a hypothetical discussion or a prelude to an activity in which students will test their solutions.

6.d Evaluate Understanding	Teacher encourages students to use metacognitive strategies to evaluate their own understanding of a concept. Students may be asked to evaluate how well they understand a concept, recognize misconceptions or flaws in their thinking, or judge their level of success or failure in an activity.
Practice 7: Engaging in Argument from Evidence Argumentation is common in scientific circles. Scientists may develop competing explanations and theories, especially when theories are new or when there is little information available or it is difficult to obtain. Scientific claims require support from evidence and reasoning, and arguments must be evaluated for validity and consistency. When students disagree in science, they should be encouraged to support their arguments with evidence, prior knowledge, or logical reasoning.	
7.a Disagreement	Teacher encourages and accepts multiple conflicting answers, ideas, or explanations from students. Student answers are not judged as right or wrong and emphasis is placed on obtaining multiple viewpoints.
7.b Evidence	Teacher asks students to support statements or conclusions with evidence, knowledge, or reasoning. Students are encouraged to provide support for their own thoughts and ideas.
Practice 8: Obtaining, Evaluating, and Communicating Information Because science consists of vast amounts of information that is continually being expanded, scientific knowledge must be recorded, communicated, and read by any who would seek to learn about or contribute to the field. Since scientific literature can be complex and highly technical, students should be exposed to it early and often in order to become familiar with its style and to develop their scientific vocabulary. Students should also learn what resources are available to obtain scientific information, how to use those resources and which of those resources are valid and unbiased sources. Students should also practice communicating their own scientific knowledge – orally and in writing – clearly, concisely, and comprehensively.	
8.a Documentation	Teacher or students record information generated during the lesson on paper, a chalkboard, or some other medium. Relevant information must be student-generated, such as students' ideas or discussions, or data obtained from an experiment, such as measurements or observations. This information can be in the form of verbal writing, numerical data, or a drawing.
8.b Vocabulary	Teacher uses appropriate science vocabulary in context during a lesson, rather than simply defining the word or asking students for a definition. The teacher reinforces the vocabulary word for students by using it in context throughout the lesson.
8.c Open-ended Question	Teacher asks questions that encourage students' own thoughts and ideas. Questions that ask students to choose from a set of pre-selected options are NOT open-ended.
8.d Sequenced Questions	Teacher uses multiple questions on a particular topic to lead students to higher levels of thinking or to move from general to specific concepts. There must be a student response between questions, and follow-up questions build on students' answers to previous questions.
8.e Clarification	Teacher asks the student to restate an unclear response or to elaborate on an incomplete response with questions such as ''What do you mean?'' or ''Can you say more about that?'' Clarification questions do not ask specifically for new information, but ask students to clarify or elaborate on their own.
8.f Expository Text	Teacher incorporates expository text into the science lesson. The expository text may be print or electronic.
8.g Technology	Teacher has students use electronic devices, such as computers or iPads, during the science lesson, or the teacher uses the technology with student involvement.
8.h Assessment	Teacher uses formative assessments during the lesson to evaluate student understanding, either through questioning or by asking students to submit a product for evaluation.