Yuan, J., Kim, C., Hill, R., & Kim, D. (2019). Robotics integration for learning with technology. Contemporary Issues in *Technology and Teacher Education 19*(4), 708-735.

Robotics Integration for Learning With Technology

Jiangmei Yuan
West Virginia University

ChanMin Kim
The University of Georgia, Pennsylvania State University

Rogers Hill & Dongho Kim
The University of Georgia

This qualitative study examined how preservice elementary teachers integrated robotics into science, technology, engineering, and mathematics (STEM) lesson designs and why they designed their lessons in a particular way. Participants' lesson designs were collected, and semistructured interviews were conducted. The authors analyzed lesson designs to examine how participants integrated robotics into their lesson designs and interviews to explore why they designed their lessons in a particular way. Our findings suggest that, in general, preservice elementary teachers designed lessons for student learning with technology. Only one lesson was for student learning from technology. The rest were for student learning with technology or applied a mixed approach that supported both student learning with and from technology. Preservice teachers' lesson designs seemed to have been influenced by their pleasant struggles during robot design, collaboration experience, robotics integration knowledge, STEM content knowledge, and conception of STEM integration. Implications for teacher education are presented.

Science, technology, engineering, and mathematics (STEM) education is critical in strengthening the STEM workforce in the 21st century (Becker & Park, 2011). The STEM workforce plays a critical role in meeting future occupational needs, fostering innovation, and strengthening the competitiveness of a nation (National Science Board, 2015).

STEM knowledge is essential for not only STEM occupations but also non-STEM occupations (National Science Board, 2015). Student STEM achievement in the United States, however, has been lower than in other nations (Adams, Miller, Saul, & Pegg, 2014; National Science Board, 2010). A decade ago, a declining trend in the number of K-12 students interested in STEM careers was noted (Apedoe, Reynolds, Ellefson, & Schunn, 2008) and, more recently, a shortage of qualified STEM personnel (National Science Board, 2015).

The teaching of STEM subjects in elementary grades is important because the elementary school years are a critical time for students to develop a STEM interest (Adams et al., 2014). However, elementary teachers face multiple challenges in teaching STEM. First, they are known to have limited STEM content knowledge (Davis, Petish, & Smithey, 2006; Li, 2008). Second, they have tended to have anxiety about, negative attitudes toward, and low confidence in teaching STEM subjects (Adams et al., 2014; Bursal & Paznokas, 2006; Philippou & Christou, 1998). Third, many teachers have not been found to be well prepared to teach engineering (Rogers, Wendell, & Foster, 2010) although the discipline of engineering is critical for preparing future citizens for a technical world and educating future engineers.

An integrated approach has been used in teaching STEM (Czerniak & Johnson, 2014; Johnson, 2013). The problems of life are not based on a single discipline; rather, they are multidisciplinary in nature, calling for knowledge from different areas (Czerniak & Johnson, 2014). An integrated approach allows students to see connections among different fields and develop problem-solving and critical thinking skills (Elliott, Oty, McArthur, & Clark, 2001).

Moreover, this approach sparks students' interest in STEM by highlighting the usefulness and relevance of STEM knowledge in their lives (Petrie, 1992). Students can also develop critical thinking skills when an integrated approach is employed in STEM teaching.

The qualitative study described in this article examined how preservice elementary teachers integrated robotics into STEM lesson designs and why they designed their lessons in a particular way. It was part of a teacher professional development and research project that aimed to prepare preservice elementary teachers to integrate robotics into their teaching. This article, when discussing major findings, also provides suggestions for teacher education programs that prepare teachers to teach STEM in elementary classrooms.

Relevant Literature

Educational Robotics

Concrete objects such as manipulatives have been used to teach children abstract concepts for many years (Bers & Portsmore, 2005). Educational robots are newer manipulatives and conducive to STEM learning in various ways. Robotics can spark students' interest in STEM subjects (Rogers & Portsmore, 2004); assembling and programming robots provides students with opportunities to learn mathematics, physics, and engineering concepts (Bers, 2008); and hands-on robotics activities provide students with occasions to apply abstract STEM knowledge (Bers, 2008; Nugent, Barker, Grandgenett, & Adamchuk, 2010).

Research has shown that robotics can enhance student learning in science (Whittier & Robinson, 2007), technology (Barker & Ansorge, 2007), engineering (Barker & Ansorge, 2007; Kaya, Newly, Deniz, Yesilyurt, & Newley, 2017), mathematics (Highfield, 2010;

Hussain, Lindh, & Shukur, 2006), and programming (Jaipal-Jamani & Angeli, 2017). Moreover, robotics activities can enhance students' three-dimensional thinking skill, facilitate their development of technological literacy (Bers, 2008), and attract them to technology-related careers (Nugent et al., 2010).

Whether young children can benefit from robotics might be a concern for educators. Prior research shows that children as young as 4 years old are able to build and program robots (Cejka, Rogers, & Portsmore, 2006; Kazakoff, Sullivan, & Bers, 2013). Robotics provides an environment for young children to learn engineering concepts (Resnick, 2017) and programming (Bers, Flannery, Kazakoff, & Sullivan, 2014), and creates a context for them to experiment with their ideas and develop creative thinking skills (Resnick, 2017). Since educational interventions that begin earlier have a more enduring impact than those implemented later in children's lives (Reynolds, Temple, Ou, Arteaga, & White, 2011), it is appropriate to integrate robotics into early learning curriculum.

Teacher Education in Educational Robotics

Many teachers are familiar with technology, but they still need to learn about technology integration (Mueller, Wood, Willoughby, Ross, & Specht, 2008). Teacher education is important, since technology is evolving over time. Past studies have found that the majority of teachers are not prepared to integrate robotics into classroom teaching (Mataric, Koenig, & Feil-Seifer, 2007), so there is a need to train teachers to use robotics in their classrooms.

Technology integration training should start in teacher education programs (Kay, 2006). Preservice teachers' technology experience in their teacher education programs constitutes a critical factor affecting their use of technology in the classroom as new teachers (Tondeur et al., 2012). In addition, preparing preservice teachers to teach STEM with robotics can be an effective strategy to enhance students' STEM learning (Jaipal-Jamani & Angeli, 2017). It is important for preservice teachers to learn how to integrate educational robotics into their classrooms (Bers, 2008; Kim et al., 2015).

Learning from Technology Versus Learning with Technology

According to Jonassen's (2000) typology of the different purposes of using technology, when the instructor uses technology to deliver instruction and transmit knowledge, technology is a delivery tool and students are involved in learning *from* technology. Students are recipients of knowledge, and what they produce is a replicate of the information delivered to them (Jonassen, Howland, Marra, & Crismond, 2008).

In contrast, when technology is used as a cognitive tool for information access, analysis, and knowledge organization, representation, and interpretation, students learn *with* technology (Jonassen & Reeves, 1996). To achieve meaningful learning outcomes, students need to be involved in learning with technology (Ertmer & Ottenbreit-Leftwich, 2013; Jonassen & Reeves, 1996).

A learning environment supporting student learning with technology is akin to a student-centered learning environment. In a student-centered learning environment, students take an active role in their learning. They are involved in seeking information from various resources, exploring, organizing knowledge, and creating artifacts to represent their knowledge (Brush & Saye, 2000; Hannafin & Land, 1997).

Theoretical Framework: Experiential Learning

Our approach was guided by experiential learning, which mainly rests on Dewey's pragmatism, Lewin's social psychology, and Piaget's cognitive development (Kolb, 1984). According to this perspective, learning consists of four stages: concrete experience, reflective observations, generalizations, and applications. When working on robotics projects, learners can learn from the concrete experience of building, programming, and designing robots, observe what their peers are doing, develop hypotheses (Kim, Yuan, Vasconcelos, Shin, & Hill, 2018), and apply what they have generalized from their experience to new situations (Robinson, 2005). In so doing, knowledge is derived from experience.

Purpose and Research Questions

Educational robotics can be beneficial for students' STEM learning in many ways, but it has been integrated in middle and high school classrooms more than in elementary ones (Bers, 2008). Research on how to prepare teachers to integrate robotics into elementary classrooms is needed, but few studies have examined how preservice elementary teachers develop their ability to incorporate robotics into K-12 classrooms.

Kim et al. (2015) examined preservice teachers' STEM engagement in and learning from a robotics learning module, as well as their STEM teaching. Ortiz, Boz, and Smith (2015) investigated participants' reactions toward a robotics module that focused on the engineering design process, programming, and mathematics. Jaipal-Jamani & Angeli (2017) focused on the impact of a robotics project on preservice teachers' self-efficacy in using robotics for teaching and learning, science learning, and computational thinking skills. Kim et al. (2018) examined how preservice teachers debugged errors when they programmed their robots.

This study adds to the literature an in-depth examination of preservice teachers' integration of robotics into their lesson designs. The central research questions guiding this study were as follows:

1. *How* do preservice elementary teachers integrated robotics into their lessons?
2. *Why* do preservice elementary teachers designed their lessons in a particular way?

We analyzed preservice elementary teachers' lesson designs to study how they integrated robotics into their lessons, and we conducted semistructured interviews to investigate why they designed their lessons in a particular way.

Method

Design

The purpose of this study was to examine the features of preservice teachers' lesson plans integrating robotics into elementary classrooms and determine why they designed their lessons in a particular way. This study used a grounded theory approach to finding out reasons for preservice teachers' lesson designs. A grounded theory approach was employed because it can help researchers generate an explanation of an action or process that is drawn from data (Strauss & Corbin, 1998).

Participants and Setting

Participants were 19 preservice teachers from an undergraduate elementary education course offered at a public university in the southeastern United States. Eight participants were from one section; eight from another; and three from a third section. These three sections were taught by three instructors in the same program. One participant was a male student, and the rest were female.

All participants were majoring in early childhood education. The course objectives included designing technology-enhanced activities for elementary students, introducing students to the engineering design process, and conducting research on age-appropriate instructional strategies and principles.

In the remainder of this paper, the elementary education course is referred to as "the course." All three sections included a robotics learning module. All instructors used the same robotics learning module in which participants (a) were introduced to educational robotics, (b) assembled and programmed robots in groups, (c) individually designed lessons for elementary classrooms, and (d) created a poster presenting what they had learned and how they were able to use robotics for elementary education.

Data Collection Procedure

Participants' lesson designs for using robotics in elementary classrooms were collected, and semistructured interviews were conducted after the completion of the robotics learning module. There were 19 lesson designs and 19 interviews. Each interview was about 30 minutes long and audio recorded.

The interview questions asked preservice teachers what their learning experience was in the robotics learning module, how they created their lesson plans, what STEM content knowledge they learned, and what they learned about teaching STEM. The questions on preservice teachers' learning experience were created on what Fredricks et al. (2004) suggested about the engagement framework; as engagement "has the potential to link areas of research about antecedents and consequences of how students behave, how they feel, and how they think" (p. 82).

Example interview questions included the following:

- "How did you feel while you were working on robotics activities in this class?"
- "Please talk about the lesson plan that you came up with using robotics."
- "What new STEM content or processes did you learn?"
- "How would you use what you learned from these robotics activities in your teaching?"

Data Analysis

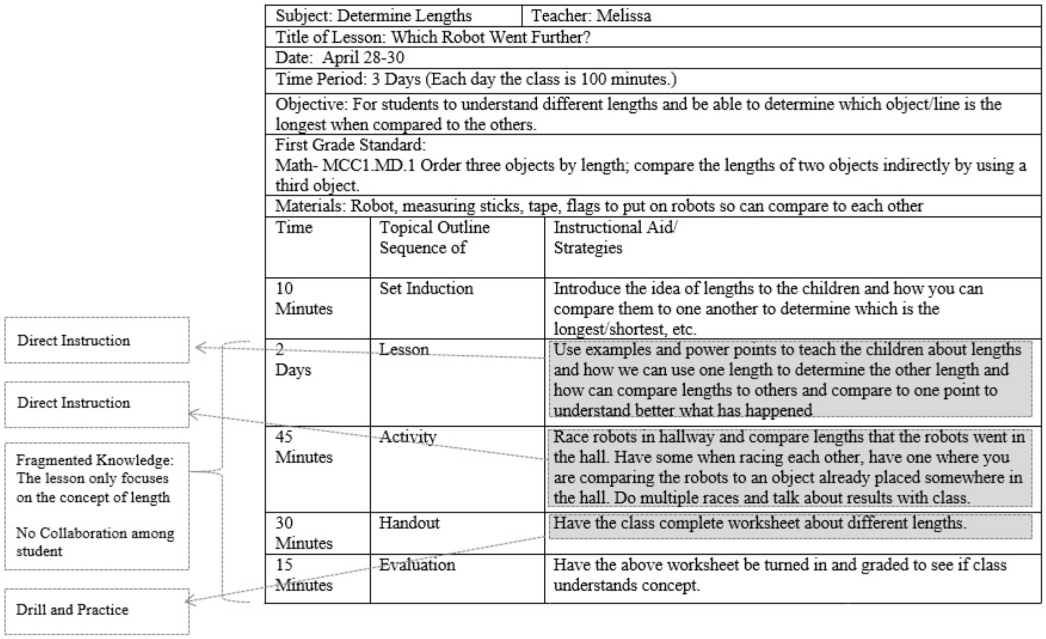
Lesson designs were analyzed to examine the features of teachers' technology integration practice, and interviews were analyzed to gain insights into the factors affecting such practice. The concept of student-centeredness (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012) was used for lesson design analysis. The student-centeredness instrument consists of seven criteria: teacher role, student role, curricular characteristics, classroom social organization, assessment practices, technology role, and technology content (p. 427).

We selected two criteria from the student-centeredness instrument — curricular characteristics and technology role — to analyze the lessons through the lens of learning *with* technology vs. learning *from* technology. These two criteria were selected because they focused on whether or not teaching emphasized students' collaboration, information access, knowledge construction, knowledge application, and problem solving (see Table 1).

Table 1
Criteria From Student-Centeredness Instrument (Ertmer et al., 2012, p. 427) Used in This Study

Teacher-Centered	**Student-Centered**
Curricular Characteristics	
Breadth — focus on externally mandated curriculum	Depth — focused on student interests
Focus on standards	Focus on understanding of complex ideas
Fact retention	Application of knowledge to authentic problems
Fragmented knowledge and disciplinary separation	Integrated multidisciplinary themes
Technology Role	
Drill and practice	Exploration and knowledge construction
Direct instruction	Communication (collaboration, information access, expression)
Programming	Tool for writing, data analysis, problem-solving

If instructors ensured that students used technology for information access, knowledge organization, collaboration, and problem solving (Jonassen et al., 2008; Jonassen & Reeves, 1996) and instructors created an authentic learning environment in which students applied their knowledge (Jonassen et al., 2008), they were facilitating student learning *with* technology. The criteria of *curricular characteristics* and *technology role* allowed us to investigate whether and how learning STEM *with* technology was designed in these lessons. Table 1 lists the two criteria of the student-centeredness instrument used in this study. The Appendix and Figure 1 illustrate how lesson designs were analyzed.



Subject: Determine Lengths	Teacher: Melissa	
Title of Lesson: Which Robot Went Further?		
Date: April 28-30		
Time Period: 3 Days (Each day the class is 100 minutes.)		
Objective: For students to understand different lengths and be able to determine which object/line is the longest when compared to the others.		
First Grade Standard: Math- MCC1.MD.1 Order three objects by length; compare the lengths of two objects indirectly by using a third object.		
Materials: Robot, measuring sticks, tape, flags to put on robots so can compare to each other		
Time	Topical Outline Sequence of	Instructional Aid/ Strategies
10 Minutes	Set Induction	Introduce the idea of lengths to the children and how you can compare them to one another to determine which is the longest/shortest, etc.
2 Days	Lesson	Use examples and power points to teach the children about lengths and how we can use one length to determine the other length and how can compare lengths to others and compare to one point to understand better what has happened
45 Minutes	Activity	Race robots in hallway and compare lengths that the robots went in the hall. Have some when racing each other, have one where you are comparing the robots to an object already placed somewhere in the hall. Do multiple races and talk about results with class.
30 Minutes	Handout	Have the class complete worksheet about different lengths.
15 Minutes	Evaluation	Have the above worksheet be turned in and graded to see if class understands concept.

Figure 1. *Analysis of a lesson for student learning from technology (the instructor's name is a pseudonym).*

Our data analysis consisted of the following steps: (a) reading lesson designs to gain an understanding of them; (b) analyzing the features of the lesson designs and categorizing them using the two criteria from the student-centeredness instrument, (c) reading interviews to acquire an understanding of them, (d) connecting participants' lesson designs to their interview to further examine why the participant designed the lesson in a particular way, and (e) considering all reasons to look for themes.

To discover why participants designed their lessons in a particular way, we analyzed interviews by following the three phases of coding for developing grounded theory — open, axial, and selective coding (Strauss & Corbin, 1990). In the open coding phase, we used the constant comparative approach to examine the interviews to look for major categories of reasons. In the second phase, axial coding, we made connections among the categories. In the third phase, we built a "story" connecting the categories.

Trustworthiness

We sought to produce trustworthy results as we designed and conducted this study. To this end, we followed the standards delineated by Lincoln and Guba (1985). Credibility was gained through using multiple data sources and researchers. Data included lesson designs and interviews. All researchers were actively involved in research design, data collection, and data analysis. We held regular meetings to discuss the recruitment of participants, the development of our interview protocol, and the search for and selection of the instrument to analyze lesson designs. Three authors discussed how to analyze lesson designs and interviews. Two of us analyzed one lesson design and interview individually.

We agreed on the features of the lesson plan but disagreed on one reason for the lesson design. We discussed our disagreement and then analyzed another lesson and interview independently. We discussed and agreed on the lesson features and reasons for the design. Despite our agreement, we still discussed our thoughts regarding the analysis. One of the two authors then analyzed one fifth of the remaining lesson designs and interviews, and the other did the rest.

One of the two authors analyzed then one fifth of the remaining lesson designs and interviews, and the other did the rest. Based on multiple rounds of independent coding and discussions and reaching consensus between coders, the analysis was consistent between different coders throughout the entire coding process.

Results

This section is a summary of how participants integrated robotics into their lesson designs and the data indicating why they designed their lessons in a particular way. We selected illustrative quotes from interviews to represent themes we identified. Pseudonyms are used.

How Participants Integrated Robotics Into Their Lessons

The ways in which participants integrated robotics into their lesson designs fell into three categories: supporting student learning *with* technology, supporting student learning *from* technology, and supporting student learning both *with* and *from* technology (mixed). The lessons categorized as mixed exhibited some (but not all) of the features of supporting student learning with technology and all features supporting student learning from technology. Table 2 illustrates the features of the three categories of lesson designs and lists examples of each feature from students' lesson designs.

Learning with technology. Eleven lesson designs facilitated student learning with technology. Features in the lessons are listed in Table 2, which also includes an example from participants' lesson designs for each feature.

1. Students' skill in accessing information was emphasized (information access).
2. More than one discipline was incorporated (multidisciplinary).
3. Students were required to assemble and program robots collaboratively (collaboration).
4. Students were given the opportunity to apply their learned content outside of classroom (e.g., how they would use a robot in their everyday lives; application).
5. Students explored the functions of robots (exploration) and used other technologies to communicate about their robot assembly and programming (expression).

One example lesson design for student learning with technology integrated robotics into teaching language arts by asking students to assemble and program robots and then write a reflection paper. Students needed to collaborate with their group members to assemble and program robots. For the reflection paper, they needed to think about how they could apply the skills they had learned from the lesson to other circumstances. They were also expected to research and describe the careers they could pursue with computer programming skills, which involved information access and knowledge application.

Table 2
Lesson Design Features and Examples for Each Feature

Lesson Design Feature	**Examples for Each Feature**
Learning With Technology	
Info Access	Students research careers related to computer programming. Students conduct a research on NASA missions robots perform and how robots are used in our daily lives.
Multidisciplinary [a]	A lesson integrates technology, science, and language arts.
Collaboration [a]	Students work in groups to assemble and program robots.
Application [a]	Students write a narrative essay describing a space mission during which a rover is used to explore a planet. Students should incorporate what they have learned about the planets and robots in space exploration. Students write an essay describing how their lives would be different if there were more robots around.
Expression [a]	Students make a poster showing what they did when they assembled and programmed their robots. Students write in the KWL (already know, want to know, learn) chart what they knew and what they would like to know about robotics.
Problem Solving [a]	Students test their robots after they program them (When students test their robot, if the robot does not run as they expect, students need to solve programming problems.)
Data analysis	Students use a scale to weigh the pieces of a robot and the robot to test the theory that the weight of an object is equal to the sum of the pieces that are used to build the object.
Learning From Technology	
Drill and Practice [a]	Students assemble and program one robot and then assemble and program another robot. They then create a poster to show what they learned. The teacher races robots he/she has assembled and programmed in the hallway multiple times. Students complete worksheets about comparing lengths. The teacher grades the worksheets to see if students understand the concept of length.
Direct Instruction [a]	The teacher uses examples and PowerPoint to teach students about lengths. The teacher then uses PowerPoint slides to explain the function of robots and teaches students how to program robots by demonstration.

Lesson Design Feature	Examples for Each Feature
Disciplinary Separation [a]	The lesson design only focuses on the concept of length. The teacher runs a robot already assembled and programmed and asks students to measure the distances. The teacher assembles and programs a Racebot before class and shows the robot in class. Students in the class reprogram the robot together. They then assemble and program their own Racebot with their group. After the completion of the activity, the teacher asks students what they learned and what was challenging.

Mixed. Seven lesson designs were created to facilitate student learning both with and from technology and student learning from technology. The features supporting student learning with technology included all features listed in the previous section except for information access (see Table 2). The features of student learning from technology include direct instruction, drill and practice, and disciplinary separation.

One example lesson design in this category connected engineering and language arts to science. This lesson focused on the uses of robots in exploring space and the rover on Mars, which was part of the science curriculum. Students were also introduced to the engineering process to construct the Mars Rover by watching a video, and they were required to write an essay describing a space mission on which a rover was used to explore a planet of their choice.

To introduce the lesson topic, the teacher gave students an opportunity to explore the functions of a duck robot. The teacher then presented the use of robots in exploring space with an electronic slideshow. The slideshow presentation was a means of student learning from technology.

Learning from technology. One lesson was designed for student learning from technology. In this lesson design, the teacher presented the concept of length through an electronic slideshow. Direct instruction was involved. The teacher then raced robots multiple times, and students practiced comparing the distances the robots had run. Students learned how to compare lengths through drill and practice.

Why Participants Designed Their Lessons in a Particular Way

The interviews suggested several reasons as to why participants designed their lessons in a particular way. This section describes the reasons and provides illustrative quotes for each. The reasons are presented as themes, and pseudonyms were used to protect participants' identity.

For each theme, the lesson participants designed is described, the lesson design features are summarized, the reasons for the design features are reported, and quotes from participants to represent the theme are included. Figure 2 illustrates the reasons participants' lesson designs had features supporting learning with technology or learning from technology.

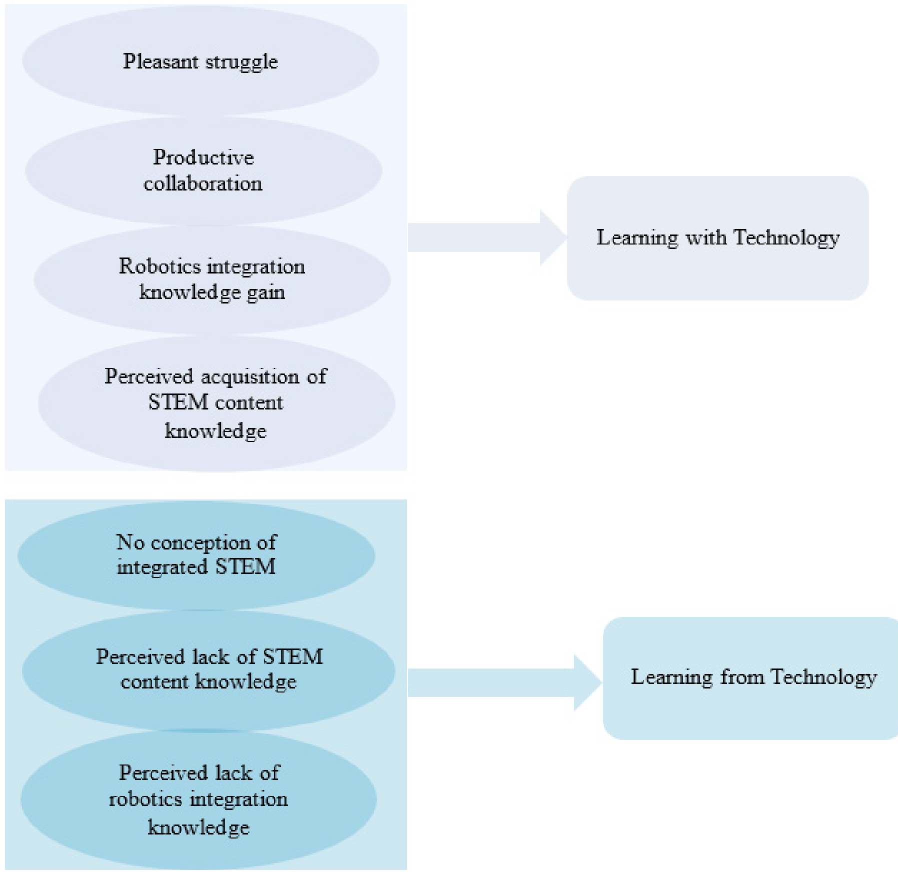


Figure 2. *Reasons participants' lesson designs had features supporting learning with technology or learning from technology*

Interviews suggest four reasons (Themes 1-4) for designing lessons with features supporting student learning with technology (see Figure 2). The lesson designs used as examples include those supporting learning with technology as well as mixed lesson designs. The interviews of participants who designed mixed lessons (lesson designs with features supporting student learning with technology and student learning from technology) also suggested reasons their lesson designs exhibited features supporting student learning with technology.

Theme 1: Participants' own enjoyable struggle with robot design provided inspiration for designing lessons that involved student-centered problem-solving. Some participants' lessons required students to write about how robots can be used to solve problems. This design feature seemed to be a result of participants' *enjoyable* struggle during a problem-solving experience.

For example, in Patricia's lesson, students assembled and programmed their robots to run in a square-shaped path. Students tested their robots upon completion of programming, recorded videos of their robots running, and posted their videos online. The teacher assisted students if they needed help with programming. Students also compared their robot to two other groups' robots and reflected on the robotics activity and how well their robots performed. When students tested their robot, they needed to solve programming problems if the robot did not perform as expected.

Patricia's own experience of struggle and problem solving seemed to have contributed to the design of this activity. She said most of their difficulties were with programming the robot, and she described one challenge in detail:

> The difficulties we had were mostly with the program. … We had difficulty because we set different speeds. We set it too fast or too slow, and we didn't know how long it should turn for. We definitely had to use trial and error to figure out the exact time we had for the robot to turn for and how fast do it.

She also mentioned that once her group solved their problem, she liked programming, explaining, "But once we figured out how to program it, I liked it." The experience of finding solutions to problems seemed to have motivated Patricia to design a lesson in which students tested their robots and solved programming problems.

Theme 2: Participants' collaborative robotics work was reflected in their lesson designs. One feature of the lessons designed by participants was asking students to work collaboratively on projects. Students needed to work with their group members to assemble robots, program them, or write robot stories. This feature seemed to be a product of participants' collaboration experience in the course.

In Kate's lesson, for example, fifth graders constructed a robot of their choosing with their group members. The teacher provided assistance as needed. Students presented their robots and wrote a reflection paper on what they had learned and enjoyed during the process. In this student-centered lesson, students needed to collaborate with their group members. This design appeared to be influenced by Kate's own collaboration experience. She reported that she had had fruitful collaboration with her partner and did not have to work on the robotics activities outside of the class:

> I didn't [have to come to class early and leave late to complete the tasks], which is part of having a good partner, and then we work well together. I think that's a huge thing. I mean, you have to have good collaboration with this robotics activity, because you have to build it together, program it together, and it wouldn't be beneficial if one builds it and one does the programming. So you have to work well together.

In Layla's lesson, students built and programmed a robot of their choosing with their group members. Students wrote individually about the importance of robotics, what it took for them to put their robots together, and how multiplication and division were involved in programming their robots. Then, as a group, they wrote a story about how their robots helped sustain a healthy Earth.

Students worked collaboratively to assemble and program their robots and to write a story as well. This feature of Layla's lesson seemed to have been influenced by her learning with her partner during the robotics learning module, as indicated in her comment:

> We were both learning about robotics together, like we didn't really have a ton of knowledge on it. So it was a learning experience for both of us. And I think that way it was more fun, because we were both, like, just playing around and trying to figure things out together. Like I said before, two minds are working on one thing.

Layla said if she used robots in her class in the future, she would have students work in pairs:

> I feel like it's a lot easier to pair up, because I know if I had to do it by myself, it would have taken a lot longer than it actually did, and pairing up, it's like having two creative minds being able to put more into what they will be able to do with their robot.

As suggested by participants' remarks, they not only worked productively when collaborating on robot assembly and programming but also learned together. The experience seemed to have made it natural for them to design lessons requiring collaborative work.

Theme 3: Participants' perceived learning of robotics integration was conducive to their lesson design for student learning with technology. Some participants whose lesson designs supported student learning with technology reported that what they learned from the course about how to integrate robotics into teaching was a valuable source for their lesson design ideas. For example, Kate created a lesson for fifth graders to construct a robot of their choosing with their group members. The teacher provided assistance as needed. Students presented their robots and wrote a reflection paper on what they had learned and enjoyed during the process. This lesson design supported student collaboration in class and integrated technology with language arts. Kate stated that she designed her lesson by modifying the robotics activity in the course:

> What I did was kind of took what we were doing as a class and made it just a little bit easier for the students, future students' classroom, and that way, I just felt like the way we approached in the classroom, like the discussion-based, and everything, that was good standards to keep.

In the course, robotics was used for student learning with technology: Students assembled and programmed robots collaboratively, explored their robots' functions, designed lessons integrating robotics into teaching, and created posters presenting their robot assembly and programming. Kate designed her lesson by modifying the course activities, which explains why her lesson design supported student learning with technology.

What Jane learned from the course about how robotics could be integrated into teaching also played a role in her lesson design. One of her lesson objectives was for students to be able to observe and describe the function of parts of an object. The students and teacher had a discussion on the importance of parts for an object. Students were then given a worksheet with pictures of objects and asked how the objects would function without certain parts.

They collaboratively assembled robots, which were then programmed by the teacher. The teacher showed how the program told the robot what to do and how each part functioned. Students wrote a reflection paper on the importance of parts for an object.

This lesson required students to work in groups and integrated technology and science. Jane stated that the robotics activities in the course were important for her: "I guess as a future teacher trying to teach kids about STEM knowledge and that kind of stuff, yes, it [the robotics activity in the course] is important." She also indicated that one major thing she learned from the robotics activity was "incorporating this activity with lesson plans to reinforce standards."

Theme 4: Participants' acquisition of STEM knowledge from the robotics activities was instrumental in STEM lesson designs for student learning with technology. Participants perceived that STEM content knowledge acquired from the course contributed to the design of STEM lessons for student learning with technology. For example, Patricia designed a lesson in which students assembled and programmed their robots to run in a square-shaped path. Students tested their robots upon completion of the programming, recorded videos of their robots running, and posted their videos online. They then compared their robots to two other groups' robots and reflected on the activity and on how their robots performed.

Patricia's lesson integrated science (i.e., used recording devices for capturing information) and technology. Patricia noted that the technology knowledge she had acquired from the course was instrumental in designing her lesson. She said, "I learned a lot of stuff, like what goes into the program and how to make the robot move, make the robot turn." She then continued to point out that "since we've built up over the semester the knowledge of that, we were able to do this [design lessons]."

In Anne's lesson, students built and programmed their robot in groups, came up with real-life applications of the robot they built, and presented their robots to the class. After that, the teacher asked students what they enjoyed or did not enjoy about the activities and how engineering could benefit from robotics work. Students wrote a narrative using correct sequencing and a detailed description.

This lesson integrated technology, engineering, and language arts. Anne said that she came to see herself as "a more knowledgeable person about technology and engineering," which seems to have helped with the STEM lesson design.

Reasons for Designing Lesson Features That Support Learning From Technology

Three reasons (Themes 5-7) for designing lessons with features supporting student learning from technology are described in Figure 2. The example lesson designs presented in this section include lessons supporting learning from technology and mixed lesson designs. We include mixed lesson designs because the interviews of the participants creating mixed lessons also suggest reasons they designed lessons with features supporting student learning from technology.

Theme 5: Participants' conception that STEM subjects should not be taught in a multidisciplinary way for young children led to disciplinary separation. Participants' conception that STEM subjects should not be taught in a multidisciplinary way at the elementary level led to lesson designs focusing on one single subject. Melissa's lesson was to teach students about length and how to compare lengths in a mathematics class. The teacher raced robots already assembled and programmed in the hallway multiple times. Students completed worksheets about comparing the distance the robots had traveled. The teacher graded the worksheets to see if students understood the concept of length. Students worked individually on the lesson.

The robots were used to help students learn the concept of length through drill and practice, such as repeatedly comparing the distances that the robots traveled. Melissa pointed out that science was not a primary discipline for young students, which was the rationale for not including science in her lesson design. She also noted that STEM was more important for older elementary level students, not for younger ones.

In her lesson, first graders were taught the concept of length through the teacher's lecture. Her decision to teach a single mathematical concept taught through drill and practice can be attributed to her belief that basic knowledge should be the focus for younger grades, as indicated in the following remark: "I think that for the younger ages, it's more about the basics, so that you can get them to that knowledge in the older grades." She went on to elaborate on how the integrated STEM ideas would confuse young students:

> I think you need to build the foundation in younger ages, when they get to the older elementary, you can really go more in-depth with the STEM knowledge, because I think if you just brought complex ideas at them without that base knowledge at the younger grades, they are just confused then. I think you use STEM more as you get older. I think they are like more like middle, high school STEM knowledge and stuff.

Theme 6: Participants' perceived lack of STEM knowledge led to lesson designs in which students learn concepts through drill and practice. Participants' perceived that lack of STEM knowledge led to the lesson design features supporting student learning from technology, especially drill and practice. Joan's lesson design demonstrated a mixed approach (i.e., support for student learning with and from technology). In her lesson, students practiced assembling and programming two robots collaboratively. They made a poster showing what they did and why robot assembling and programming did or did not work.

The features supporting student learning with technology included collaboration and students expressing what they did and why it did or did not work through posters. However, students learned assembling and programming skills by drill and practice — assembling and programming two robots. Also, the subject specified in the lesson was only technology.

Joan's perception of her lack of STEM knowledge probably led to a lack of multidisciplinary inclusion. Joan stated that she had not learned much about STEM during her school years and specifically mentioned her lack of knowledge about engineering despite the robotics learning module in the course emphasizing engineering processes.

Theme 7: Participants' perceived lack of robotics integration knowledge led to lesson designs focusing on robot assembly and programming. Eva designed a lesson supporting student learning with technology and from technology. In her lesson, the teacher reviewed instructions on how to build robots. Students assembled robots in groups and decided how they wanted their robots to be programmed. The teacher then programmed the robots for the students. The teacher and students went over how the programming and the robots were connected by exploring different components of the programming, including chips, DC motors, delays, and so forth.

Collaboration was a feature supporting student learning with technology. The teacher used direct instruction to explain how to build robots, and the lesson was not multidisciplinary, only focusing on technology. These were the features of student learning from technology.

Eva's lack of knowledge of how to integrate robotics into STEM teaching led to her lesson design that focused only on robot assembly and programming. For example, she stated, "I am not sure exactly how I would connect to it (mathematics)." She also said, "I don't really think the engineering and technology part relates well [to robotics activities]." Although technology was the focus of her lesson, she did not believe that robotics activities are related to the subject of technology.

Discussion

Findings and Interpretations

Educational robotics have been increasingly used in K-12 classrooms. However, few studies have examined how preservice teachers develop the skills to teach STEM by integrating robotics into their classrooms (Jaipal-Jamani & Angeli, 2017). This study adds to the literature on how preservice teachers use robotics in their lesson designs and what influenced the ways in which they integrated robotics into the lesson designs.

Our findings suggest that, in general, these future elementary teachers created lessons for student learning with technology. Only one lesson was for student learning from technology. The rest of the lesson designs gave students the opportunity to learn with technology or they applied a mixed approach that supported students' learning both *with* and *from* technology. Preservice teachers' lesson designs seemed to have been influenced by their *enjoyable* struggles during robot design, collaboration experience, robotics integration knowledge, STEM content knowledge, and conception of STEM teaching.

One key finding of this study is that the majority of preservice teachers designed lessons that aimed to support student learning *with* technology. The first feature of these lesson designs is that students needed to test the robots they programmed, which provided them with an opportunity to solve problems. If the robot did not perform as they expected, they needed to diagnose what the problem is, generate and evaluate solutions, and decide on how to solve the problem. Thus, students are likely to achieve meaningful learning outcomes (Jonassen & Reeves, 1996).

Second, most lessons required students to assemble and program robots collaboratively and reflect on the robotics activities. Through these activities, students constructed artifacts and solved problems. They were not simply recipients of information delivered to them (as described in Jonassen et al., 2008). Specifically, students applied programming knowledge to make their robots perform certain behaviors. When students encountered problems during robot assembly and programming, they analyzed the problems and found solutions.

The majority of the lessons also asked students to reflect on their hands-on activities in group discussions or writing assignments. Students were given opportunities to think about the problems arising in their learning process, the causes of the problems, and what they learned from the experience. This process supports knowledge construction (Jonassen & Reeves, 1996) through experiential learning.

Third, among the multidisciplinary lesson designs, the most commonly integrated subjects were technology and language arts. One common activity was to ask students to engage in writing, that is, to write about the problems robots can solve or write about their robotics experience. By so doing, students can become storytellers and develop technological fluency (Bers, 2008).

One notable finding is that preservice teachers' enjoyable struggle with the robotics activities motivated them to design lessons incorporating problem-solving activities. The robotics learning module in the course allowed for struggle in the process of solving problems encountered during assembling and programming robots and designing lessons.

As reported in the interview, the overwhelming majority of the preservice teachers had no prior educational robotics experience, especially in programming robots. In this study, they needed to design (i.e., decide on the robot to assemble and program), assemble, and program their robot as well as designing a lesson using the robot. Although there was a manual for robot assembly and basic programming (e.g., programming the robot to run along a straight line), preservice teachers struggled with problems such as connecting the wires to the ports and programming the speed for each motor.

Struggle does not mean “needless frustration or extreme level of challenges” (Hiebert & Grouws, 2007, p. 387). It refers to making an effort to understand something not obvious. Most preservice teachers in this study exerted a considerable amount of effort to solve their problems and enjoyed the problem-solving process.

For example, when asked whether she enjoyed the robotics activities, one preservice teacher said yes, and then she continued to state, “They were kind of frustrating a little bit when they didn’t work out but, it was fun learning them, yeah. For sure.” Another preservice teacher said, “I enjoyed the robotics activity. I did a lot. I liked it.” Later, she mentioned that programming was difficult and she was unsure of it.

The struggle preservice teachers experienced promoted their engagement in learning (as also asserted by Handa, 2003) and provided a learning environment in which they could reconstruct their understanding (as in Hiebert & Grouws, 2007). Their enjoyable struggle may have motivated them to create a similar learning experience for their students.

Although student struggles in learning mathematics have been examined (e.g., Granberg, 2016; Lynch, Hunt, & Lewis, 2018; Warshauer, 2015), few studies have examined struggles in integrated STEM classrooms, especially preservice teachers’ struggles in robotics enhanced learning contexts. An implication this study provides for teacher education is that instructors can create a robotics learning environment for preservice teachers to experience struggle, which gives preservice teachers an opportunity to make sense of new information and construct knowledge by overcoming difficulties and solving problems (Granberg, 2016).

Technology integration knowledge plays an important part in teaching. In this study, preservice teachers’ acquisition of how to integrate robotics into teaching was instrumental in their lesson designs. Some preservice teachers’ lessons resembled the robotics module in the course. These preservice teachers stated explicitly that they started from the robotics activities in the course when designing their lessons, which can be explained by the fact that the way teachers have been taught influences how they teach (Adamson et al., 2003; McDermott, 2006).

On the other hand, preservice teachers’ perceived lack of robotics integration knowledge seemed to have led to lesson designs that focused exclusively on robot assembly and programming. The lessons designed by Joan, Eva, and Bella consisted of one major activity — students assembling and programming robots. The robotics activity was not connected to any other content area. During the interview, these preservice teachers reported that they neither considered robotics to be related to technology and engineering, nor did they know how to connect robotics to science and mathematics.

Teachers need to see how a new technology can be used to enhance teaching in a particular content area to see the value of the technology (Hughes, 2005; Ottenbreit-Leftwich, Glazewski, Newby, & Ertmer, 2010) and to learn how to use the technology effectively for instructional purposes (Dexter, Doering, & Riedel, 2006; Sutton, 2011). These preservice teachers had not experienced robotics before, and examples of how robotics could be used to teach specific content areas were not provided in this study, which is a possible reason why they designed a lesson focused only on assembling and programming robots, not on teaching their subject area.

One implication is that teacher education programs need to provide teachers with content-specific training. This goal can be realized by case-based learning, which helps teachers build a connection between their knowledge and a specific context, and helps teachers understand the intricacies of instructional decision making as well (Doyle, 1990; Han, Eom, & Shin, 2013).

Another strategy is to require instructors in teacher education programs to model the use of technologies in the subject areas preservice teachers will be teaching in the future. Learning technology integration strategies is one benefit of modeling (Ertmer, Conklin et al., 2003). Preservice teachers' self-efficacy regarding robotics integration could also be improved after observing how the technology is used by their instructors.

Third, preservice teachers can be given opportunities to learn through design. In a design-based learning context, preservice teachers can use real-life skills and knowledge to work on projects. Therefore, the new knowledge preservice teachers acquire and the skills they develop in such contexts can be transferred to the real world (de Vries, 2006; Ke, 2014). However, research shows that preservice teachers feel they have little experience designing activities incorporating technology (Tondeur et al., 2012). A design-based learning environment can be created for preservice teachers to help them devise their robots and lessons.

Participants' conception that STEM subjects should not be taught in an integrated way at the lower elementary level led to lesson designs focusing on a single subject. Traditionally, STEM subjects are taught as separate disciplines (Parker, Abel, & Denisova, 2015), which is how these preservice teachers were taught in elementary school. They probably learned from their own educational experience that STEM subjects should be taught in isolation to young children. However, real-world problems are multidisciplinary in nature, and knowledge and skills from multiple disciplines are necessary for solving the problems (Johnson, 2013; Roehrig, Moore, Wang, & Park, 2012). An integrated approach is needed to prepare the future workforce (English, King, & Smeed, 2017).

Also, students' interests in STEM need to be nurtured when they are young (English & King, 2015). Therefore, an integrated STEM approach should be applied to elementary education. The implication on teacher education is that efforts need to be made to prepare preservice elementary teachers to teach integrated STEM subjects. These efforts include providing preservice teachers with courses delivered in an integrated way (Johnson, 2013) and helping preservice teachers learn instructional principles, pedagogical content knowledge, and STEM literacy for STEM integration (Rinke, Gladstone-Brown, Kinlaw, & Cappiello, 2016).

An integrated STEM approach is not a "convenient integration" of the four subjects, however (English et al., 2017; STEM Task Force Report, 2014). Rather, STEM should be integrated through real-world problems that connect these disciplines through active teaching and learning.

A lack of STEM knowledge seems to constitute one of the reasons for preservice teachers' designing lessons for student learning from technology. Preservice teachers' acknowledgement of their lack of STEM knowledge is consistent with findings of prior studies reporting that many preservice teachers do not have adequate STEM knowledge (Cunningham, Knight, Carlsen, & Kelly, 2007; Davis, Beyer, Forbes, & Stevens, 2011;

Papadouris, Hadjigeorgiou, & Constantinou, 2014), especially elementary teachers (Davis et al., 2006).

Teachers need to have content knowledge, first and foremost, to teach well, since teachers' content knowledge significantly affects how the content will be taught (Gess-Newsome & Lederman, 1995). Additionally, an integrated approach to STEM teaching requires sufficient content knowledge (Berlin & White, 2012). Teacher education programs need to make efforts to enhance preservice teachers' STEM content knowledge. Preservice teachers would benefit significantly from STEM content courses taught in an integrated way, since preservice teachers tend to apply an integrated method to STEM teaching after they have been taught in such a way (Czerniak & Johnson, 2014).

Limitations of the Study and Future Research

The findings should be interpreted with caution due to several limitations. First, only lesson plans and interviews were analyzed. Teaching requires more than lesson planning (Shoffner, 2009). Preservice teachers' technology integration practices are also influenced by their field experiences (Belland, 2009). Future studies can observe preservice teachers' student teaching or in-service teachers' practice in the classroom.

Second, as the preservice teachers in our study assembled and programmed robots with their group members, they might also have discussed lesson plans. However, little is known about the lesson plan conversations in the groups. An examination of the discussions preservice teachers have with their group members could help us understand why they design their lesson plans in a particular way.

Another direction for future research is a follow-up study with these same preservice teachers investigating how they integrate robotics in their classrooms after they become in-service teachers. When preservice teachers designed their lessons, they did not take into account any difficulties they might encounter in elementary schools. The follow-up study could provide us with information about what influences in-service teachers' robotics integration practices.

In addition, a potential analytic view that future research can take is learning *through* technology. When preservice teachers were immersed in the robotics activity, they were probably learning through technology. An examination of their experience can provide more insights into the design of a learning environment enhanced by robotics.

Author Note

The initial work was done at the University of Georgia, but revisions were done while ChanMin Kim was at Pennsylvania State University. Dongho Kim is now at the University of Florida.

References

Adams, A. E., Miller, B. G., Saul, M., & Pegg, J. (2014). Supporting elementary preservice teachers to teach STEM through place-based teaching and learning experiences. *Electronic Journal of Science Education, 18*(5). Retrieved from https://files.eric.ed.gov/fulltext/EJ1188278.pdf

Adamson, S. L., Banks, D., Burtch, M., Cox III, F., Judson, E., Turley, J. B., ... Lawson, A. E. (2003). Reformed undergraduate instruction and its subsequent impact on secondary school teaching practice and student achievement. *Journal of Research in Science Teaching, 40*(10), 939–957.

Apedoe, X. S., Reynolds, B., Ellefson, M. R., & Schunn, C. D. (2008). Bringing engineering design into high school science classrooms: The heating/cooling unit. *Journal of Science Education & Technology, 17*(5), 454–465.

Barker, B. S., & Ansorge, J. (2007). Robotics as means to increase achievement scores in an informal learning environment. *Journal of Research on Technology in Education, 39*(3), 229–243.

Becker, K. H., & Park, K. (2011). Integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A meta-analysis. *Journal of STEM Education: Innovations and Research, 12*(5–6), 23–37.

Belland, B. R. (2009). Using the theory of habitus to move beyond the study of barriers to technology integration. *Computers & Education, 52*(2), 353–364.

Berlin, D. F., & White, A. L. (2012). A longitudinal look at attitudes and perceptions related to the integration of mathematics, science, and technology education. *School Science & Mathematics, 112*(1), 20–30.

Bers, M. U. (2008). Engineers and storytellers: Using robotic manipulatives to develop technological fluency in early childhood. In O. N. Saracho & B. Spodek (Eds.), Contemporary perspectives on science and technology in early childhood education (pp. 105–125). Charlotte, NC: Information Age.

Bers, M. U. (2010). The TangibleK robotics program: Applied computational thinking for young children. *Early Childhood Research & Practice, 12*(2), 1–19.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education, 72*, 145–157. https://doi.org/10.1016/j.compedu.2013.10.020

Bers, M. U., & Portsmore, M. (2005). Teaching partnerships: Early childhood and engineering students teaching math and science through robotics. *Journal of Science Education & Technology, 14*(1), 59–73.

Brush, T., & Saye, J. (2000). Implementation and evaluation of a student-centered learning unit: A case study. *Educational Technology Research & Development, 48*(3), 79–100.

Bursal, M., & Paznokas, L. (2006). Mathematics anxiety and preservice elementary teachers' confidence to teach mathematics and science. *School Science & Mathematics, 106*(4), 173–180.

Cejka, E., Rogers, C., & Portsmore, M. (2006). Kindergarten robotics: Using robotics to motivate math, science, and engineering literacy in elementary school. I*nternational Journal of Engineering Education, 22*(4), 711–722.

Cunningham, C. M., Knight, M. T., Carlsen, W. S., & Kelly, G. (2007). Integrating engineering in middle and high school classrooms. *International Journal of Engineering Education, 23*(1), 3–8.

Czerniak, C. M., & Johnson, C. C. (2014). Interdisciplinary science teaching. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (pp. 395–411). New York, NY: Routledge.

Davis, E. A., Beyer, C., Forbes, C. T., & Stevens, S. (2011). Understanding pedagogical design capacity through teachers' narratives. *Teaching and Teacher Education, 27*(4), 797–810.

Davis, E. A., Petish, D., & Smithey, J. (2006). Challenges new science teachers face. *Review of Educational Research, 76*(4), 607–651.

de Vries, E. (2006). Students' construction of external representations in design-based learning situations. *Learning & Instruction, 16*(3), 213–227.

Dexter, S., Doering, A. H., & Riedel, E. S. (2006). Content area specific technology integration: A model for educating teachers. *Journal of Technology & Teacher Education, 14*(2), 325–345.

Doyle, W. (1990). Case methods in the education of teachers. *Teacher Education Quarterly, 17*(1), 7–15.

Elliott, B., Oty, K., McArthur, J., & Clark, B. (2001). The effect of an interdisciplinary algebra/science course on students' problem solving skills, critical thinking skills and attitudes towards mathematics. International Journal of Mathematical *Education in Science & Technology, 32*(6), 811–816.

English, L. D., & King, D. (2015). STEM learning through engineering design: Fourth-grade students' investigations in aerospace. *International Journal of STEM Education, 2*(14). Retrieved from https://stemeducationjournal.springeropen.com/articles/10.1186/s40594-015-0027-7

English, L. D., King, D., & Smeed, J. (2017). Advancing integrated STEM learning through engineering design: Sixth-grade students' design and construction of earthquake resistant buildings. *The Journal of Educational Research,* 110(3), 255-271. https://doi.org/10.1080/00220671.2016.1264053

Ertmer, P. A., Conklin, D., Lewandowski, J., Osika, E., Selo, M., & Wignall, E. (2003). Increasing preservice teachers' capacity for technology integration through use of electronic models. *Teacher Education Quarterly*, 30(1), 95–112.

Ertmer, P. A., & Ottenbreit-Leftwich, A. (2013). Removing obstacles to the pedagogical changes required by Jonassen's vision of authentic technology-enabled learning. *Computers & Education, 64*, 175–182.

Ertmer, P. A., Ottenbreit-Leftwich, A. T., Sadik, O., Sendurur, E., & Sendurur, P. (2012). Teacher beliefs and technology integration practices: A critical relationship. *Computers & Education, 59*(2), 423–435. https://doi.org/10.1016/j.compedu.2012.02.001

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research, 74*(1), 59–109.

Gess-Newsome, J., & Lederman, N. G. (1995). Biology teachers' perceptions of subject matter structure and its relationship to classroom. *Journal of Research in Science Teaching, 32*(3), 301.

Granberg, C. (2016). Discovering and addressing errors during mathematics problem-solving—A productive struggle? *Journal of Mathematical Behavior, 42*, 33–48.

Han, I., Eom, M., & Shin, W. S. (2013). Multimedia case-based learning to enhance preservice teachers' knowledge integration for teaching with technologies. *Teaching and Teacher Education, 34*, 122–129.

Handa, Y. (2003). A phenomenological exploration of mathematical engagement: Approaching an old metaphor anew. For the Learning of Mathematics, 23(1), 22–29.

Hannafin, M. J., & Land, S. M. (1997). The foundations and assumptions of technology-enhanced student-centered learning environment. *Instructional Science, 25*(3), 167.

Hiebert, J., & Grouws, D. A. (2007). The effects of classroom mathematics teaching on students' learning. In F. K. Lester (Ed.), Second handbook of research on mathematics teaching and learning: A project of the National Council of Teachers of Mathematics (pp. 371–404). Charlotte, NC: Information Age Pub.

Highfield, K. (2010). Robotics toys as a catalyst for mathematics problem solving. *Australian Primary Mathematics Classroom, 15*(2), 22–27.

Hughes, J. (2005). The role of teacher knowledge and learning experiences in forming technology-integrated pedagogy. *Journal of Technology and Teacher Education, 13*, 277–302.

Hussain, S., Lindh, J., & Shukur, G. (2006). The effect of lego training on pupils' school performance in mathematics, problem solving ability and attitude: Swedish data. *Journal of Educational Technology & Society, 9*(3), 182–194.

Jaipal-Jamani, K., & Angeli, C. (2017). Effect of robotics on elementary preservice teachers' self-efficacy, science learning, and computational thinking. *Journal of Science Education and Technology, 26*(2), 175–192.

Johnson, C. C. (2013). Conceptualizing integrated STEM education. *School Science & Mathematics, 113*(8), 367–368.

Jonassen, D. H. (2000). *Computers as mind tools for schools: Engaging critical thinking*. Upper Saddle River, NJ: Merrill.

Jonassen, D. H., Howland, J., Marra, R., & Crismond, D. (2008). *Meaningful learning with technology*. Upper Saddle River, NJ: Pearson/Merrill Prentice Hall.

Jonassen, D. H., & Reeves, T. C. (1996). Learning with technology: using computers as cognitive tools. In D. H. Jonassen (Ed.), *Handbook of researcher for educational* *communications and technology* (pp. 693–719). Bloomington, IN: Association for Communications and Technology.

Kay, R. H. (2006). Evaluating strategies used to incorporate technology into preservice education: A review of the literature. *Journal of Research on Technology in Education, 38*(4), 383–408.

Kaya, E., Newly, A., Deniz, H., Yesilyurt, E., & Newley, P. (2017). Introducing engineering design to a science teaching methods course through educational robotics and exploring changes in views of preservice elementary teachers. *Journal of College Science Teaching, 47*(2), 66–75.

Kazakoff, E., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal, 41*(4), 245–255.

Ke, F. (2014). An implementation of design-based learning through creating educational computer games: A case study on mathematics learning during design and computing. *Computers & Education, 73*, 26–39.

Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education, 91*, 14–31. https://doi.org/10.1016/j.compedu.2015.08.005

Kim, C., Yuan, J., Vasconcelos, L., Shin, M., & Hill, R. B. (2018). Debugging during block-based programming. *Instructional Science, 4*(6), 767–787. https://doi.org/10.1007/s11251-018-9453-5

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Upper Saddle River , NJ: Prentice Hall.

Li, Y. (2008). Mathematical preparation of elementary school teachers: Generalists versus content specialists. *School Science & Mathematics, 108*(5), 169–172.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, CA: Sage Publications.

Lynch, S. D., Hunt, J. H., & Lewis, K. E. (2018). Productive struggle for all: Differentiated instruction. *Mathematics Teaching in the Middle School, 23*(4), 194–201.

Mataric, M. J., Koenig, N., & Feil-Seifer, D. (2007, March). *Materials for enabling hands-on robotics and STEM education*. Paper presented at the AAAI Spring Symposium on Robots and Robot Venues, Stanford, CA.

McDermott, L. C. (2006, September). Preparing K-12 teachers in physics: Insights from history, experience, and research. *American Journal of Physics*, 74(9), 758–762.

Mueller, J., Wood, E., Willoughby, T., Ross, C., & Specht, J. (2008). Identifying discriminating variables between teachers who fully integrate computers and teachers with limited integration. *Computers & Education, 51*(4), 1523–1537.

National Science Board. (2010). *Science & engineering indicators 2010.* Retrieved from https://www.heri.ucla.edu/PDFs/NSB.pdf

National Science Board. (2015). *Revisiting the STEM workforce: A companion to science and engineering indicators 2014.* Retrieved from http://www.nsf.gov/nsb/publications/2015/nsb201510.pdf

Nugent, G., Barker, B., Grandgenett, N., & Adamchuk, V. I. (2010). Impact of robotics and geospatial technology interventions on youth STEM learning and attitudes. *Journal of Research on Technology in Education, 42*(4), 391–408.

Ortiz, A. M., Bos, B., & Smith, S. (2015). The power of educational robotics as an integrated STEM learning experience in teacher preparation programs. *Journal of College Science Teaching, 44*(5), 42.

Ottenbreit-Leftwich, A. T., Glazewski, K. D., Newby, T. J., & Ertmer, P. A. (2010). Teacher value beliefs associated with using technology: Addressing professional and student needs. *Computers & Education, 55*, 1321–1335.

Papadouris, N., Hadjigeorgiou, A., & Constantinou, C. (2014). Preservice elementary school teachers' ability to account for the operation of simple physical systems using the energy conservation law. *Journal of Science Teacher Education, 25*(8), 911–933.

Parker, C., Abel, Y., & Denisova, E. (2015). Urban elementary STEM initiative. *School Science & Mathematics, 115*(6), 292–301.

Petrie, H. G. (1992). Interdisciplinary education: Are we faced with insurmountable opportunities? *Review of Research in Education, 18*(1), 299–333.

Philippou, G. N., & Christou, C. (1998). The effects of a preparatory mathematics program in changing prospective teachers' attitudes towards mathematics. *Educational Studies in Mathematics, 35*(2), 189–206.

Resnick, M. (2017). *Lifelong kindergarten: Cultivating creativity through projects, passion, peers, and play*. Cambridge, MA: The MIT Press.

Reynolds, A. J., Temple, J. A., Ou, S.-R., Arteaga, I., & White, B. A. B. (2011). School-based early childhood education and age-28 well-being: Effects by timing, dosage, and subgroups. *Science, 333*(6040), 360–364.

Rinke, C. R., Gladstone-Brown, W., Kinlaw, C. R., & Cappiello, J. (2016). Characterizing STEM teacher education: Affordances and constraints of explicit STEM preparation for elementary teachers. *School Science & Mathematics, 116*(6), 300–309.

Robinson, M. (2005). Robotics-driven activities: Can they improve middle school science learning? *Bulletin of Science, Technology & Society, 25*(1), 73–84.

Roehrig, G. H., Moore, T. J., Wang, H.-H., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics, 112*(1), 31–44.

Rogers, C., & Portsmore, M. (2004). Bringing engineering to elementary school. *Journal of STEM Education: Innovations and Research, 5*(3–4), 17–28.

Rogers, C., Wendell, K., & Foster, J. (2010). The academic bookshelf: A review of the NAE report, engineering in K-12 education. *Journal of Engineering Education, 99*(2), 179–181.

Shoffner, M. (2009). The place of the personal: Exploring the affective domain through reflection in teacher preparation. *Teaching & Teacher Education, 25*(6), 783–789.

STEM Task Force Report. (2014). *Innovate: A blueprint for science, technology, engineering, and mathematics in California public education*. Retrieved from https://www.cde.ca.gov/pd/ca/sc/documents/innovate.pdf

Strauss, A., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Newbury Park, CA: Sage.

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (2nd ed.). Newbury Park, CA: Sage.

Sutton, S. (2011). The preservice technology training experiences of novice teachers. *Journal of Digital Learning in Teacher Education, 28*(1), 39–47.

Tondeur, J., van Braak, J., Sang, G., Voogt, J., Fisser, P., & Ottenbreit-Leftwich, A. (2012). Preparing preservice teachers to integrate technology in education: A synthesis of qualitative evidence. *Computers & Education, 59*(1), 134–144.

Warshauer, H. K. (2015). Productive struggle in middle school mathematics classrooms. *Journal of Mathematics Teacher Education, 18*(4), 375–400.

Whittier, L. E., & Robinson, M. (2007). Teaching evolution to non-English proficient students by using lego robotics. *American Secondary Education, 35*(3), 19–28.

Appendix
Analysis of a Lesson for Student Learning With Technology
(The instructor's name is a pseudonym)

Multidisciplinary: Language Arts, Technology, and Engineering. Although the participant indicated here that one of the standards is a science standard, the lesson design shows that science is not integrated in the lesson. Assembling and programming robots is technology.

Engineering

<table>
<tr><td colspan="2">Subject: Robotics</td><td>Teacher: Anne</td></tr>
<tr><td colspan="3">Title of Lesson: Robotics and Creative Writing</td></tr>
<tr><td colspan="3">Standard Covered:
ELACC5W3: Text Types and Purposes: Write narratives to develop real or imagined experiences or events using effective technique, descriptive details, and clear event sequences.
S5CS3. Students will use tools and instruments for observing, measuring, and manipulating objects in scientific activities.</td></tr>
<tr><td colspan="3">Date: April 20, 2014</td></tr>
<tr><td colspan="3">Time Period: 3 day period (One class period on one day is about 100 minutes.)</td></tr>
<tr><td colspan="3">Objectives:
• Learn about robotics programming and real life applications of robotics
• Explore robotic materials and programming software
• Create and program any robot in groups of two
• Respond to a creative writing prompt about the robot
• Present robots and explain their functions to the class</td></tr>
<tr><td colspan="3">Materials:
• Legos or My Robot Time materials and programming software
• Computers for each group
• Construction paper to mount writing samples
• Paper and pencil</td></tr>
<tr><td>Time</td><td>Topical Outline Sequence of Activities</td><td>Instructional Aids/Strategies</td></tr>
<tr><td>10 minutes</td><td>Introduction of the Lesson</td><td>Ask them what they think a robot is and what types of uses there are for robots. Have a class discussion about why robotics relates to engineering.</td></tr>
<tr><td>10 minutes</td><td>Introduction of Materials</td><td>Have an example of a programmed robot ready to show the class. This will get them excited and they will form an idea of how the materials all come together to make the final product. Have the sets of materials prepared prior to the lesson and assign groups at this point.</td></tr>
<tr><td>50 minutes</td><td>Robot Construction</td><td>Give the students time to choose and create their robot using the materials available. Monitor student work to eliminate simple construction mistakes.</td></tr>
<tr><td>50 minutes</td><td>Programming of Robots</td><td>This part will be very hectic and students need to follow the directions and examples in the guidebooks very closely. Because all</td></tr>
</table>

		of the groups will have different robots, they won't have an example to refer to if they need it. Programming may take several attempts and students might need to make adjustments based on their goal for the robot.
60+ minutes (as needed)	Creative Writing Activity	This is an individual portion of the lesson. Students will respond to a prompt that asks them to write a narrative about their robot. They will have few guidelines other than proper grammar, complete sentences and structured paragraphs. The students should be able to write the narrative using sequencing and detailed description. These assignments will be mounted on the wall outside of the classroom. They will be graded according to the guidelines previously mentioned.
15-30 minutes	Trial Run and Adjustment Period	Students will have a period of time to test their robots once again and ensure that they have completed the programming properly.
60 minutes (as needed)	Presentation of robots	Groups will present their robots to the class. They should state the purpose of their programming and demonstrate the robot's ability to perform the applied program. Students should come up with some hypothetical real life applications for their robot and its program. Students will be graded on their effort and organization during their presentation. They will not be graded on the accuracy of their program.
20-30 minutes	Class Discussion to review	Ask students what they enjoyed/didn't enjoy about the activity. Have them discuss why robotics is important and how engineering could benefit from robotics work.

Collaboration

Language Arts

Problem Solving

Expression

Knowledge Application

Engineering