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Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching

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A R T I C L E I N F O

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A B S T R A C T

We report a research project with a purpose of helping teachers learn how to design and implement science, technology, engineering, and mathematics (STEM) lessons using robotics. Specifically, pre-service teachers' STEM engagement, learning, and teaching via robotics were investigated in an elementary teacher preparation course. Data were collected from surveys, classroom observations, interviews, and lesson plans. Both quantitative and qualitative data analyses indicated that pre-service teachers engaged in robotics activities actively and mindfully. Their STEM engagement improved overall. Their emotional engagement (e.g., interest, enjoyment) in STEM significantly improved and in turn influenced their behavioral and cognitive engagement in STEM. Their lesson designs showed their STEM teaching was developing in productive directions although further work was needed. These findings suggest that robotics can be used as a technology in activities designed to enhance teachers' STEM engagement and teaching through improved attitudes toward STEM. Future research and teacher education recommendations are also presented.

Teachers greatly influence student interest in science, technology, engineering, and mathematics (STEM) and STEM career pursuit (Duschl, Schweingruber, & Shouse, 2007). For this reason, STEM education has been emphasized in middle and high schools (Murphy & Mancini-Samuelson, 2012). Still, teacher influence on STEM interest and career pursuit is largely overlooked at the elementary level. STEM education is weaker in primary schools than in secondary schools (Hossain & Robinson, 2012) despite the prolonged impact of elementary students' career interests on their career choices (Archer et al., 2013; Maltese & Tai, 2010).

Elementary teachers need to be equipped with STEM content knowledge. Only 30% of elementary education programs at the undergraduate level require pre-service teachers to take a science course (Greenberg, McKee, & Walsh, 2013). Graduate-level elementary teacher education programs do not fare much better; 56% of such programs do not require candidates to have taken a science course at the graduate level (Greenberg et al., 2013). Science and mathematics are clearly subjects that elementary school teachers must teach, but the extent to which they master these subjects is largely limited by the exposure they have had to these content areas. Thus, many elementary teachers simply teach what they remember from science classes they took when in K-12 schooling (Nadelson et al., 2013). Furthermore, the methods they use to teach the content largely

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mirror how they were taught (Belland, 2009; Windschitl, 2004). Thus, if teacher preparation informed by authentic science inquiry is not sufficiently provided, teachers will likely teach STEM in either a lecture-driven manner (Belland, 2009) or guided by pseudoscience (Chinn & Malhotra, 2002; Windschitl, 2004).

Through the current research, we examined elementary teachers' STEM content knowledge as well as their preparation to teach STEM. This research has the potential to help teacher education programs better prepare teachers to influence STEM interest and career investigation by elementary students. The specific purpose of this research was to investigate pre-service teachers' STEM engagement, learning, and teaching when using robotics technology.

1. Literature review

1.1. Teacher engagement, learning, and practice

Without engagement, learning hardly occurs. Engagement is defined in this research as behavioral, cognitive, and emotional participation (Fredricks, Blumenfeld, & Paris, 2004). Teacher learning is not an exception. To learn to teach STEM, teachers ought to engage in the learning process. There has been a little research on how to engage elementary teachers in the process of STEM learning for teaching. In Adams, Miller, Saul, and Pegg (2014), pre-service elementary teachers engaged in using the connection between students and their local, real-world environments, called a place-based education approach, to teach mathematics, science, and social studies. As a result, their confidence in STEM teaching and intent to teach STEM increased; however, teaching engineering was not explicit in their learning process. DiFrancesca, Lee, and McIntyre (2014) described an elementary teacher preparation program in which the engineering design process was integrated into mathematics and science teaching courses. Although pre-service teachers' attitudes toward and confidence in teaching engineering improved, they did not acknowledge their engagement in the interconnected engineering, science, and mathematics courses. However, *integrative* learning and teaching of STEM is crucial (Becker & Park, 2011). Robotics enables interdisciplinary work (Bers, 2008). Robotics is a motivating, learning tool due to its encouragement of experiential, hands-on learning (Matarić, Koenig, Nathan, & Feil-Seifer, 2007; Nugent, Bradley, Grandgenett, Adamchuk, 2010; Osborne, Thomas, & Forbes, 2010). As motivation is the basis of engagement (Martin, 2012), thus, robotics can be used as a tool to engage teachers in integrative learning and teaching of STEM.

1.2. Robotics and STEM education

Robotics can be effective in teaching STEM (Altin & Pedaste, 2013; Barker, Nugent, & Grandgenett, 2008, 2014; Matarić, Koenig, & Feil-Seifer, 2007) because it enables real-world applications of the concepts of engineering and technology and helps to remove the abstractness of science and mathematics (Nugent et al., 2010). In fact, various robotics activities led to improvements in science, technology, engineering, and/or mathematics learning. For example, robotics led to the enhancement of (a) mathematics performance among elementary and middle school students, especially average achievers (Lindh & Holgersson, 2007), (b) science performance among elementary students (Karahoca, Karahoca, & Uzunboylub, 2011), (c) physics content knowledge among middle school students (Williams, Ma, Prejean, Ford, & Lai, 2007), (d) engineering design skills among middle school students (Larkins, Moore, Rubbo, & Covington, 2013), and (e) STEM knowledge among elementary and middle school students (Barker, Grandgenett, Nugent, & Adamchuk, 2010). The use of robotics also positively influenced the abilities that are critical in STEM learning and performance such as spatial ability (Coxon, 2012), interpreting graphs (Mitnik, Recabarren, Nussbaum, & Soto, 2009), and picture sequencing (Kazakoff, Sullivan, & Bers, 2013). In addition, other benefits related to STEM have been reported. STEM interest was fostered among a wide range of K-12 students (Osborne et al., 2010). Motivation was promoted (McGill, 2012; Petre & Price, 2004) through improved self-confidence (Osborne et al., 2010) and especially less negative emotional experience such as anxiety among inner-city students (Goldman, Eguchi, & Sklar, 2004). Other benefits from the use of robotics that have been found are improvement in communication and collaboration skills, problem-solving, and creative thinking (Alimisis, 2013; Beer, Chiel, & Drushel, 1999; Bers, 2008; Mitnik et al., 2009).

The common contexts in which robotics has been implemented with K-12 students are summer and afterschool programs (Barker et al., 2010; Larkins et al., 2013; Williams et al., 2007). Competitions also have been a popular context that involves many interested students in robotics activities (Altin & Pedaste, 2013). There is much evidence showing these extracurricular contexts provide opportunities for STEM learning through robotics (Barker, Nugent, & Grandgenett, 2014). However, such contexts tend to attract students who are already motivated to learn STEM (Larkins et al., 2013). To engage more students in STEM learning and careers, there is a need to approach students who are not interested in such extracurricular opportunities as well as those who are interested but cannot afford such opportunities. Thus, connecting robotics activities to curricular goals *in classrooms* should expand benefits of robotics for STEM education. However, it is rare to see robotics integrated into K-12 classrooms (Williams et al., 2007) although the use of programmable learning materials in classrooms has been advocated for more than 30 years (Papert, 1980). Only recently initiatives to integrate robotics into the STEM curriculum have begun (Arlegui, Pina, & Moro, 2013; Bers, 2008, 2010).

1.3. Teacher education on educational robotics

The majority of teachers do not recognize the benefits of educational robotics (Alimisis et al., 2007), and even when they do, many are not prepared to use robots in teaching (Matarić et al., 2007). Teachers' STEM knowledge is required to teach STEM content using robots, but a lack of teachers with STEM knowledge is a major concern in the US. Strategies such as lowering tuition have been recommended for teacher education programs in the STEM fields to recruit more future teachers and equip them with STEM knowledge (Greenberg et al., 2013). In addition, not only teachers' knowledge of STEM but also their interests in STEM are critical in teaching STEM. Interest leads to active engagement in general (Fredricks et al., 2004) and teachers' STEM knowledge in the absence of interest is less likely to impact their practice (Kim, Kim, Lee, Spector, & DeMeester, 2013).

Robotics can be an effective tool to get teachers interested in STEM and engaged in STEM learning and teaching. Teacher education on robotics also can bring about other positive influences on teacher practice such as student-centered teaching (Bers, 2008). Despite the importance of teacher education that includes educational robotics (Pittí, Curto, Moreno, & Rodríguez, 2013), there are only a few studies that involved teacher training with educational robotics. Robotics was used in a K-12 teacher development workshop focused on helping teachers understand computer science concepts and programming (Kay, Moss, Engelman, & McKlin, 2014). Teachers' confidence in and knowledge of programming as well as their efficacy in facilitating STEM teaching increased after their workshop participation. However, the workshop was on building and programing robots rather than using robots for teaching.

Even when the purpose of teacher training was clearly on the use of robots in teaching, sufficient information is rarely presented with regard to how teacher training was done as well as how its impact was investigated. Perritt (2010) described professional development using a problem-based learning approach along with robotics. The author indicated that the more confident teachers were, the more they used robots and critical thinking in teaching. However, limited information about the professional development was provided. Likewise, Osborne et al. (2010) highlighted the importance of teacher training but they only briefly mentioned the fact that teacher workshops were offered. No data were collected with regard to how the robotics workshops may have led to teacher learning and teaching outcomes. Arlegui et al. (2013) explained more about their teacher training but had only anecdotal reports on what teachers learned and did. Tocháček and Lapeš (2012) introduced a program using educational robotics as a tool to teach pre-service teachers about constructivist teaching. They provided more details than many other studies, but no results from the program have been reported.

It is even more difficult to find studies involving *elementary* school teacher training on educational robotics. However, it has been argued that no student is too young to engage in robotics activities (Matarić et al., 2007), and there is evidence of even Pre-K students' learning with robots (Kazakoff et al., 2013). Effective elementary teacher education is needed for the use of “developmentally appropriate robotics” (Bers, 2010, p. 1). For example, although Sullivan and Moriarty (2009) provided a detailed description of their professional development workshop on educational robotics and data collection, teachers were only from middle and high schools. In contrast, Bers and Portsmore (2005) introduced pre-service teachers in an early childhood education program to robotics using a partnership with engineering students. However, this study did not provide guidance for the contexts in which help from an engineer is unavailable and left it to teachers to design class activities using robotics. Instructor involvement in this study of the early childhood education program was minimal because the researchers purposefully planned to observe the natural process of pre-service teachers' collaboration with engineering students. Similarly, the focus of Sullivan and Moriarty (2009) was on a discovery learning approach that they chose as “the most congruent with the pedagogical intent of the designers of the technology [robots]” (p.130). However, the minimal instruction given to teachers in both studies makes it difficult for other researchers and educators to duplicate their teacher trainings and investigations.

In sum, there is a lack of previous research on elementary teacher learning of robotics and practice using robotics and of a systematic investigation on teachers' learning and teaching in relation to their training (See Table 1 for a summary of gaps in the literature). In the current study, we endeavored to collect “measurable evidence” (Williams et al., 2007, p. 201) that would

Table 1
Gaps in the literature.

Gaps	Relevant literature
Methods to interest teachers in STEM subjects and teaching, such as place-based learning and robotics-based learning, have been studied but “how” and “what of” the methods worked have been rarely reported	(Adams et al., 2014; Bers, 2008)
Engineering is often missing in teacher learning of STEM education	(Adams et al., 2014)
Integrative STEM is pursued but hard to be achieved	(DiFrancesca et al., 2014)
Benefits of educational robotics are not appreciated among the majority of teachers due to no learning opportunity	(Alimisis et al., 2007; Pittí et al., 2013)
More opportunities for STEM learning are offered to middle/high school teachers than to elementary school teachers	(Bers, 2010; Bers & Portsmore, 2005; Sullivan & Moriarty, 2009)
Training on building/programing robots are often highlighted rather than using robots for teaching	(Kay et al., 2014)
There is a lack of information and systematic evaluation of teacher education on robotics for teaching	(Arlegui et al., 2013; Osborne et al., 2010; Perritt, 2010; Tocháček & Lapeš, 2012)

lead to an understanding of how teachers engage in, learn about, and use robotics for teaching. We targeted pre-service teachers for elementary education acknowledging the importance of pre-service teacher education in forming their characteristics as teachers (Bers & Portsmore, 2005).

2. Research questions

This study was conducted with an undergraduate elementary education course and examined what impact teaching with robots had on pre-service teachers' STEM engagement, learning, and teaching. We addressed the following research questions:

1. How do participants engage in robotics activities?
2. Is there any change in participants' STEM engagement after participating in robotics activities?
3. Is there any change in participants' STEM learning after participating in robotics activities?
4. How does participating in robotics activities influence participants' STEM teaching?

3. Methods

3.1. Research design

We used a concurrent triangulation mixed methods design to investigate pre-service teachers' STEM engagement, learning, and teaching when using robotics technology (Creswell, Clark, & Gutmann, 2003). A mixed method was chosen because it can take advantage of both “quantitative methods (large sample size, trends, generalization) and qualitative methods (small sample size, details, in depth)” and offset the “non-overlapping weaknesses” of one method with the strengths of the other method (Creswell & Clark, 2007, p. 62). We collected quantitative and qualitative data concurrently from multiple sources: (a) students' reports of their STEM engagement and STEM knowledge through surveys before, during and/or after robotics activities, (b) lesson plans, (c) videos of robotics activities, and (d) student interviews. The priority was equal between the quantitative and qualitative methods. Data mixing occurred during interpretation, to confirm findings from the quantitative and qualitative methods.

3.2. Participants

Participants were sixteen students recruited from two sections of an elementary pre-service teacher education course at a large public university in the southeastern United States. The course was designed primarily to prepare pre-service teachers to integrate hands-on learning with elementary STEM instruction and aimed to provide them with opportunities to experience various types of classroom activities. Robotics-related activities were integrated into the course curriculum as one of the learning modules. Prior to the data analysis, one participant with an abnormal score on the STEM learning variable (i.e., the STEM content knowledge measure; described in the Methods section), more than 8 standard deviations away from the mean score, was classified as an outlier and excluded from the data analysis. All participants majored in Early Childhood Education except for one studying early childhood education as his minor and economics as his major. All but one were female. The average of participant age was 19.75 (SD = 0.25). Twelve were White (75%), two were multi-racial (12.5%), one was Asian (6.3%), and one was Black (6.3%). Prior to their research participation, fifteen (93.7%) completed three to five semesters at the university and one completed one semester.

3.3. Data collection

Table 2 lists data collection methods per research question.

Table 2
An overview of the data collection methods.

Research questions	Data collection methods
RQ1 on engagement in robotics activities	Classroom observation; Participant interview
RQ2 on STEM engagement	Surveys (Learning Self-Regulation Questionnaire, Achievement Emotion Questionnaire in Mathematics, STEM Semantics Survey); Participant interview
RQ3 on STEM learning	STEM knowledge assessment (Misconceptions-Oriented Standards-based Resources for Teachers, EiE What is Technology, EiE What is Engineering, Knowledge of Algebra for Teaching); Participant interviews
RQ4 on STEM teaching	Lesson plan scores; Participant interviews

3.3.1. Overview of procedure

The researchers went to each target section of the course to recruit participants. Those who agreed to participate were given pre-surveys. For the following three weeks, they participated in robotics activities. *My Robot Time* and *RoboRobo* robotics kits were used for these activities. In the first week, the instructor lectured on robotics and educational applications of robot assembly and programming. In the second class of the first week, participants were introduced to the components of the robot kits and exercised various assembly activities in groups. In the second week, participants learned how to program robots and began to build and program their own robots, also in groups. In the third week, participants designed instructional strategies and developed lesson plans for using their robots in an elementary school classroom, individually, but they were allowed to discuss their plans for instruction with others in the class. Activities during this time were all video-recorded. After the robotics activities were completed, post-surveys and interviews were conducted and the lesson plan materials were collected.

3.3.2. Engagement in robotics activities

Participants' classroom activities were video-recorded and analyzed using a student engagement observation protocol. The protocol was constructed based on the previous studies in which classroom observations were conducted to evaluate student engagement. Behavioral and emotional engagements were recorded using Engagement versus Disaffection with Learning (EvsD) (Skinner, Kindermann, & Furrer, 2008). Prior research shows that internal consistency of EvsD measured using Cronbach's alpha ranged from 0.61 to 0.85 for student report and from 0.81 to 0.87 for teacher report (Fredricks & McColskey, 2012). We used the teacher report section of EvsD as a checklist; for example, we recorded participants' behavioral engagement and emotional engagement using the checklist such as “In my class, this student does more than required” and “When working on classwork, this student seems to enjoy it”, respectively. To record cognitive engagement, we used the indicators of cognitive engagement from Helme and Clarke (2001). For example, when “justifying an argument” was observed during a small group collaboration, we recorded that the participant who justified an argument exhibited cognitive engagement (Helme & Clarke, 2001, p. 141).

We also conducted semi-structured interviews about participants' engagement in robotics activities. Table 3 lists interview questions along with the aims of each question and the literature used as a basis for constructing the questions.

3.3.3. STEM engagement

We administered surveys on STEM engagement using various instruments. To measure cognitive engagement, we used a modified version of the Learning Self-Regulation Questionnaire (SRQ-L) (Black & Deci, 2000). SRQ-L measures the degree to which participants exhibit autonomous or controlled motivation. Example items are “A solid understanding of STEM-related topics was important to my intellectual growth” in the autonomous motivation subscale and “I was worried that I would not get a good grade in the course if I didn't do STEM-related class activities” in the controlled motivation subscale. Previous studies report alpha reliabilities ranging from .72 to .90 (Black & Deci, 2000; Williams & Deci, 1996). According to the results of a reliability analysis, one item, “The instructor would have thought badly of me if I didn't do STEM-related class activities” was removed as it had a negative correlation with the rest of the instrument items ($r=-.056$). Scale reliabilities of the pre- and post-survey were .712 and .672 respectively.

To measure emotional engagement, we used a modified version of the enjoyment subscale from the Achievement Emotion Questionnaire in Mathematics (AEQ-M) (Pekrun, Goetz, & Frenzel, 2007) and STEM Semantics Survey (Tyler-Wood, Knezek, & Christensen, 2010) that investigates enjoyment and interest, respectively.

AEQ-M measures emotions related to achievement activities and outcomes in mathematics, and consists of three parts addressing emotions in class, during learning, and about tests (Pekrun, Goetz, & Frenzel, 2007). We excluded the part on test-

Table 3
An overview of the semi-structured interview protocol investigating engagement in robotics Activities.

Interview question	Investigating	Literature
▪ Did you (or your group) go above and beyond the class requirements with regard to robotics? ▪ Did you work on the robotics activities outside of class (other than class time)?	Behavioral engagement	(Finn & Zimmer, 2012; Reschly & Christenson, 2012; Skinner et al., 2008)
▪ Do you think robotics activities in this class are and will be useful to you? ▪ When did you feel uncertain or unsure about something while working on robotics activities in this class? How did you deal with this uncertainty? ▪ When were things difficult? How did you address the difficulty? Did you ask somebody for help? ▪ Did you plan before you began the robotics activities of the day? ▪ What kinds of distractions did you experience? ▪ How did you handle them?	Cognitive engagement	(Finn & Zimmer, 2012; Fredricks et al., 2004; Helme & Clarke, 2001)
▪ When you first learned that in this class you were going to work on robotics activities, what were your initial thoughts? ▪ Did you enjoy robotics activities in this class? ▪ How did you feel, typically, while you were working on robotics activities in this class? ▪ What did you dislike about robotics activities in this class?	Emotional engagement	(Fredricks et al., 2004; Mahatmya, Lohman, Matjasko, & Farb, 2012)

related emotions and applied the AEQ-M to measure enjoyment learners felt when they participated in the STEM-related class activities and learning. We also modified the items by replacing the word “math” with “STEM”. Participants were asked to report their emotional experience on seven five-point Likert scale items from “strongly disagree” to “strongly agree. Example items are “I look forward to my STEM-related class” in the class-related emotion subscale and “I enjoy doing my STEM-related homework so much that I am motivated to do extra assignments” in the learning-related emotion subscale. Reliabilities of the pre- and post-survey were .889 and .907.

STEM interest was measured using the STEM Semantics Survey (Tyler-Wood et al., 2010). This survey consists of five subscales measuring interests in each of science, technology, engineering, and mathematics disciplines as well as interests in STEM careers. Each subscale contains five items. Participants were asked to select how well an adjective represents their feeling about STEM disciplines and careers. For example, one item measuring interests in science shows two adjectives, “boring” and “interesting” on either side of the descriptor “To me, Science is”, and participants select a value from 1 through 7 placed between the two adjectives. Internal consistency reliabilities are reported to range from 0.78 to 0.94 (Tyler-Wood et al., 2010), which is considered to be acceptable (Clark & Watson, 1995). Reliabilities of the five subscales ranged from .763 to .950.

In addition, semi-structured interviews were conducted to obtain in-depth understanding of participants' STEM engagement. Example questions are as follows: “Please tell me about how the class robotics activities in which you engaged are related to STEM content. How was this experience? When were things difficult?”

3.3.4. STEM learning

Participants' STEM learning was assessed using the following four instruments: (a) Misconceptions-Oriented Standards-based Resources for Teachers (MOSART; Bucher, 2009), (b) EiE What is Technology, (c) EiE What is Engineering, and (d) Knowledge of Algebra for Teaching (KAT). Developed by the Science Education Department of the Harvard-Smithsonian Center for Astrophysics, MOSART was used to measure science learning (Sadler, Coyle, Cook-Smith, & Miller, 2006). MOSART has been used also to identify changes in teacher knowledge (e.g., Fisher & Frey, 2009). MOSART consists of multiple-choice items about scientific concepts and facts. The instrument contains 72 multiple-choice items from four subscales on astronomy, earth, life, and physical science, respectively. From each subscale, we selected two difficult, one medium, and one easy item based on correct answer rates reported in the MOSART tutorial (Sadler et al., 2006). Specifically, the correct answer rates ranged from 11% to 41% for the high-difficulty items, from 53% to 59% for the medium-difficulty items, and from 72% to 86% for the low-difficulty items. Example items are “which of the following is made from substances found in rocks and soil?” (earth science) and “which is one good way for humans to take good care of the environment?” (life science). For reliability, four items that appeared to be negatively correlated with the rest of items were deleted: one item from life ($r=-.269$) and physical science ($r=-.198$), and two items from earth science ($-.067$ and $-.028$) were excluded. Reliabilities of MOSART in pre-and post-survey were .617 and .531 respectively. To measure technology and engineering learning, we used two instruments, What is Technology and What is Engineering, among a series of instruments developed for the Engineering is Elementary (EiE) project (Cunningham, 2009). The EiE project was initiated in a response to a need for cultivating children's understanding and problem-solving in engineering (Cunningham, 2009). In the EiE questionnaires, participants were asked to choose yes or no to answer what kinds of work engineers do and what are examples of technology. Reliabilities of EiE engineering and technology in the pre- and post-survey ranged from .693 to .821. KAT was used to measure mathematics learning. KAT consists of two parts containing 20 questions each. Prior research shows that its reliability is .84 (Knowledge of Algebra for Teaching Project Group, 2009). We used one question from the first part and two from the second part to assess participants' algebraic knowledge. The reliability of KAT for pre- and post-test appeared to be below 0.2, which is considered to be a fair level. However, the items were not excluded because coefficient alpha value tends to be low when the number of items is low (Cortina, 1993). Further, the items were not unidimensional (Knowledge of Algebra for Teaching Project Group, 2009) so we decided the alpha value was less crucial to determine the test's reliability.

3.3.5. STEM teaching

Participants' lesson plans were evaluated to measure their STEM teaching. A rubric was used for the evaluation. The rubric was developed by the researchers to evaluate the potential effectiveness of the lessons measured mainly by (a) inclusion of multiple STEM subjects (as an indicator of *integrative* teaching of STEM), (b) use of a robot for teaching one or more portions of STEM content (as opposed to teaching robot assembly and programming only), and (c) technicality (e.g., inclusion of a lesson objective) and alignment among the subject(s), the objective(s), the activity(ies), and state Performance Standard(s). Specific evaluation criteria are presented in Table 4. Lesson plans were assigned and evaluated for a grade in the class but the evaluation for research purposes was completely independent of that. None of the research data was factored into grades for the course or was revealed to the course instructor prior to grades for the course being submitted. In addition, semi-structured interviews included questions investigating participants' STEM teaching such as “How would you use what you learned from these robotics activities for your teaching?”

3.4. Data analysis

Classroom activity recordings were analyzed using the student engagement observation protocol described in the Data Collection section to examine participants' engagement in robotics activities. To ensure inter-rater agreement on the use of

Table 4
Lesson plan evaluation criteria and description.

Evaluation criterion	Description
1. Subject Specification	The plan specifies at least one subject to be taught (e.g., math, science, social studies, etc. but not robotics; if only robotics is listed as a subject, score 0)
2. Multi-subject Inclusion	More than one subject is included (e.g., math and English; English and social studies).
3. STEM Inclusion	At least one STEM subject area is listed as a subject
4. Integrative STEM Inclusion	All STEM subject areas are listed and an engineering design problem is used within the learning activities
5. Objectives Specification	The plan includes at least one lesson objective
6. Standards Specification	The plan includes at least one standard to be met (e.g., Common Core Standards)
7. Activity Description	The description of the lesson activity is clear (e.g., if the description is insufficient, disorganized, and/or unclear, score 0)
8. Alignment among Standards/Subject/Activity	Standards are aligned with the subject, objective, and activity specified (e.g., if math is listed as a subject to teach but standards do not include any math standard, then no point is given; if a standard is on understanding of addition and subtraction but the lesson activity does not address that, score 0)
9. Robot Inclusion	A robot is included as a material (i.e., if a robot is ever used, that is, even a photo of a robot is used, score 1)
10. Robot Integration	A robot is used *in order to teach the subject* specified (e.g., if only robot assembly and programming are taught, score 0)

the protocol, two researchers analyzed one video independently, discussed their analyses, and reached a consensus. Then, they divided the remaining videos between the two of them and analyzed the rest.

Interview data were analyzed following the four steps of: (a) preparing data, including organizing data and transcribing interviews, (b) getting a deep understanding of the data through repeated thorough reading, (c) coding data, and (d) interpreting data (Ruona, 2005). Prior research-driven coding nodes were developed based on theories and prior research on learner engagement. Through repeated reading of interview transcripts, nodes were removed and revised, and additional nodes about students' experience of performing the robotics activities were added. To establish the reliability of the qualitative data analysis, we followed the procedures proposed by (Creswell & Clark, 2007). Specifically, two researchers developed nodes based on literature on learner engagement. After interviews were collected, these two researchers read several transcripts individually and then worked collaboratively to refine the nodes. Next, they coded one interview transcript, individually, and then discussed their analysis to reach consensus on the interview coding. They then coded the same interview individually again and rendered a Cohen's Kappa coefficient .809 for the analysis. Upon the coding strategy agreement, each of the two researchers analyzed half of the rest of the interviews. Nvivo 10 was used to analyze interviews.

For quantitative data, paired samples *t*-test and Wilcoxon Signed-Rank test were conducted to compare pre- and post-surveys on STEM engagement, interest and learning. Since this study compared pre- and post-tests, the normality of paired differences are essential for t-tests to have validity. The Wilcoxon Signed-Rank test was adopted when a variable was found to violate the assumption of normality, in order to yield valid results by using a non-parametric method. If data is obtained from non-normal distribution, non-parametric analysis is often considered to be more powerful (Pappas & DePuy, 2004). Descriptive statistics were used to analyze scores on lesson plans.

4. Results

4.1. RQ1: How do participants engage in robotics activities?

4.1.1. Classroom observation

The frequencies of behavioral, cognitive, and emotional engagement are presented in Table 5.

4.1.1.1. Behavioral engagement. A high level of behavioral engagement was observed overall during all phases. In Phase 1, without being distracted, participants actively discussed how to put the robot parts together with peers. For example, they thoroughly reviewed the manual to understand the assembly process and followed the procedures by actually assembling the parts into a robot. Based on such observations, the researchers recorded 1 (yes) to the behavioral engagement items such as, “In my class, this student works as hard as they can” and “When working on classwork in my class, this student appears involved”. However, referencing the manual was part of the assignment given by the instructor; thus, 0 (no) was recorded in response to the behavioral engagement item, “In my class, this student does more than required.” Participants' behavioral engagement was the highest in Phase 1 (57) and gradually decreased in Phases 2 (43) and 3 (39). In Phase 1, classwork with robots assembly seemed more visible than that in other phases with programming and lesson design. For example, lesson design in Phase 3 was a task that was done individually, not with the teammate, and involved silent writing rather than active physical involvement such as robot assembly. Behavioral disaffection was detected only once in Phase 1. One participant briefly checked her smart phone, leading the researchers to record 1 (yes) to the behavioral disaffection item, “When we start something new in class, this student thinks about other things.” Their behavioral disaffection was observed a few more times in Phases 2 (7) and 3 (4), which shows that behavioral disaffection was most frequently observed during programming. However, only one participant exhibited disengagement when encountering difficulties (“When faced with a difficult assignment, this student doesn't even try.”).

Table 5
Participant engagement and disengagement in robotics activities.

		Phase 1 assembly	Phase 2 programming	Phase 3 lesson planning
Behavioral engagement		57	43	39
Behavioral Disaffection		1	7	4
Cognitive Engagement	Individual working in Parallel	0	1	12
	Collaborative small group activity	71	41	14
	Small group interactions with teacher	12	17	3
Emotional Engagement		96	49	26
Emotional Disaffection		0	4	0

4.1.1.2. Cognitive engagement. In Phase 1, cognitive engagement in *collaborative small group activity* was the most frequently observed (71). This was recorded when participants performed questioning, completed peer utterances, exchanged ideas, or gave directions, explanations, or information in their group. However, cognitive engagement in *individual working in parallel* was not observed in Phase 1 in which classwork was performed only in groups. Cognitive engagement in *small group interactions with teacher* was observed 12 times in Phase 1 in that they asked questions to the instructor and answered the instructor's question as a group. In Phase 2, cognitive engagement in *collaborative small group activity* decreased and cognitive engagement in *small group interactions with teacher* increased. *Individual working in parallel* was observed once in the form of concentration. In contrast, in Phase 3, cognitive engagement in *individual working in parallel* was the most frequently observed (12) among three phases. Cognitive engagement in *small group interactions with teacher* was observed the least frequently but cognitive engagement in *collaborative small group activity* was observed the most frequently in Phase 3 in which classwork for lesson design was performed individually.

4.1.1.3. Emotional engagement. In Phase 1, emotional engagement was observed the most frequently in the forms of expressing enthusiasm (20), happiness (18), interests (18), enjoyment (20), and fun (20). Emotional engagement was observed less and less as interactions within groups decreased during later phases in which they worked individually on programming through the division of labor (Phase 2) and on lesson design as an individual assignment (Phase 3). Specifically, happiness, recorded using the item, “In class, this student appears to be happy”, was much less observed (7) in Phase 2 than other emotional engagement indicators. In Phase 3, interest, recorded using the item, “When we start something new in class, this student is interested”, was not observed at all whereas all the other indicators were. Emotional disaffection was observed only during Phase 2. Four participants exhibited frustration when their robots failed to move in their programmed direction. Other emotional disaffection such as boredom, anxiety, unhappiness, and anger was observed in all phases.

4.1.2. Student interview

Overall, three themes and six subthemes emerged from interviews on engagement in robotics activities: (a) behavioral engagement with intention to take initiative, (b) cognitive engagement in overcoming difficulties (through peer support; through trial and error), and (c) emotional engagement in moving from frustration to enjoyment (through a boost in confidence; through unexpected learning experience; through hands-on learning; through perceived value of learning for teaching).

4.1.2.1. Behavioral engagement. Taking initiative is an indicator of high levels of behavioral engagement. Participants were asked if they did more than class requirements and only one participant stated that she and her partner tried out different ways of programming their robot that were not needed in their class project. Participants said they would have built another robot if they had more time or more pieces for robot assembly.

4.1.2.2. Cognitive engagement. All participants stated that they had experienced difficulties. Most of the difficulties were from programming. However, participants were strategic so as to overcome difficulties, as hinted in the following comment, “I think it [the class with robotics activities] gave me more critical thinking skills because we got frustrated and we had a step-back thing. What's going wrong? What do we do next to try again?” They dealt with difficulties through a variety of ways such as seeking help from the instructor or classmates, trial and error, and studying the robot manual. For example, one participant noted:

> We were testing them [robots] out in the hallway. We were kind of like ‘How did you do that?’ We helped each other toward the end when we were all getting frustrated more. At the beginning we were just me and my partner. And then toward the end, we consulted the other group.

4.1.2.3. Emotional engagement. Participants reported frustration and nervousness as their initial emotional reactions to robotics activities. For example, one participant said, “I thought it [robotics] would be really hard because I am not very good at science and math stuff. I was nervous on how I would be able to handle it, and see how it would be. I was really overwhelmed, maybe frustrated.” Programming was the major source of frustration to participants due to no prior experience with programing but frustration also came from designing lessons. Programming was referred to as well when positive emotions were reported such as enjoyment. For example, one stated, “I really enjoyed the programming part. I think the most.” The participants, who specifically reported they had felt scared at first and exhibited a lack of confidence in robotics assembly and programming, reported their joyful experience with excitement. For example, “I mean I definitely thought it was going to be hard. Like didn't want to do it. I was not looking forward to it at all [but after the activity] I thought it was really easy. I actually really enjoyed it.” Participants' improved confidence was often highlighted as illustrated in the following comment:

> When I hear the term robotics, I usually think of what this whole society thinks, like a man job. And I'm just not familiar with a lot of technology, and robotics, and I've never worked with it, so I was nervous. And then when I saw how easy the steps were laid out, I really enjoyed it.

Unexpected processes of learning seem to have created enjoyment as one participant commented, “I really enjoyed it. It was interesting because I didn't really think I would be able to do it and I can do it.” Participants' feeling of accomplishment was enabled even more with seeing an immediate consequence of their actions:

> I definitely think the building part was really fun for me because it was, working with my partner, and then seeing the actual finished product, and having it do something. It's what I think really made it fun for me.

Hands-on learning was highlighted also as one participant stated, “I enjoy hands-on activities, so building the robot was fun for me.” All participants *valued* robotics activities. The value of building robots was highlighted despite challenges as follows: “I think it was pretty difficult to assemble it. It definitely helped that I had a partner who helped with the programming and assembly. But it was cool once it's finished. I was glad I did it.” And a new learning experience was appreciated, “Definitely it was pretty cool to build a robot. I've never built a robot before so it was pretty awesome.” The value of learning about not only how a robot works but also how it can be used for STEM teaching as a future teacher was acknowledged.

4.2. RQ2: Is there any change in participants' STEM engagement after participating in robotics activities?

4.2.1. Surveys

A paired samples *t*-test and Wilcoxon Signed-Rank test were conducted to compare pre- and post-surveys on participants' STEM engagement. Specifically, autonomous or controlled motivation, as indicators of cognitive engagement, and interest and enjoyment, as indicators of emotional engagement, were analyzed. First, to determine whether there was a violation of normality, the paired differences of all variables were analyzed using Shapiro–Wilk test. For the variables of interest in science ($p = 0.021$) and interest in engineering ($p = 0.013$), the normality assumption was not met and the Wilcoxon Signed-Rank test was used instead, thus making no assumption of the probability distribution (Gibbons & Chakraborti, 2011). All other variables without violation of normality were analyzed using a paired samples t-test. As a measure of effect size, correlation coefficient r was used to represent the strength of experimental effect (Field, 2009). This measure can be applied to both parametric and non-parametric tests and ranges from -1 (a perfectly negative correlation) to 1 (a perfectly positive correlation). In general, .1 indicates a small effect, .3 indicates a medium effect, and .5 and above indicates a large effect (Cohen, 1992). The analyses indicated that there were statistically significant changes in participant's cognitive engagement and emotional engagement in STEM after participating in the robotics activities. Specifically, autonomous motivation ($t = 2.683$, $p = 0.017$, $r = 0.26$), interests in science ($Z = -3.064$, $p = 0.002$, $r = -0.54$), interests in engineering ($Z = -3.071$, $p = 0.002$, $r = -0.54$), and enjoyment ($t = 2.335$, $p = 0.034$, $r = 0.19$) significantly increased. Table 6 presents the result from these analyses.

4.2.2. Student interview

Overall, three themes and eight subthemes emerged from interviews on STEM engagement: (a) behavioral engagement (due to newness; through full participation without distraction; due to STEM seamlessly integrated in robotics activities), (b) cognitive engagement (through being strategic; with autonomous motivation), and (c) emotional engagement (with interests in STEM; with newly developed confidence; through perceived value in STEM).

4.2.2.1. Behavioral engagement. Participants highlighted engagement with STEM that they had never had. One participant noted, “I never had this opportunity growing up. So I feel like this kind of opens up, you know, kids to see engineering, technology, and the whole STEM process.” Their full participation without distraction was also reported as follows, “It was something that I was really engaged with the whole time, and I wasn't like messing with my phone, or like thinking about other things. It was very engineering and robotics time of a day.” For example, one participant articulated her engagement in engineering through the manual, “Just the engineering design process. I like how they went through that in the manuals, and stuff like that. The manual did a very good job with breaking things down so the assembling part wasn't that difficult.”

Table 6
STEM engagement analysis results.

		Pre-survey (n = 16)		Post-survey (n = 16)				
		Result of Paired Samples t-test						
		M	*SD*	*M*	*SD*	*t*	*p*	*r*
Cognitive Engagement	Autonomous motivation	4.675	1.055	5.200	.876	2.683	**.017**	.26
Emotional Engagement	Enjoyment	2.848	.708	3.134	.795	2.335	**.034**	.19
	Interest in Technology	5.413	1.018	5.663	.835	1.416	.177	.13
	Interest in Mathematics	4.388	1.285	4.350	1.283	−.187	.854	−.01
	Interest in STEM Careers	3.875	1.235	4.275	1.542	1.250	.230	.14
		Result of Wilcoxon Signed-Rank Test						
		M	*SD*	*M*	*SD*	*Z*	*p*	*r*
Emotional Engagement	Interest in Science	4.300	1.110	4.938	1.090	−3.064	**.002**	−.54
	Interest in Engineering	4.350	1.111	4.963	1.267	−3.071	**.002**	−.54

Note. Significant effects are in bold.
Scores could range from 1–7.

However, many participants indicated that they were not cognizant of engaging in something related to STEM at the time of their engagement because it was part of building robots, as shown in the following comment.

I think we don't even think about using it but we just like automatically used it when we are going through an activity now, just because we are thinking about it and planning out our steps, and coming up with ways because we tested robots so many times and then improved it and thought about what changes needed to make. We obviously didn't write down like the design process but I think we just naturally do it now with the activity.

4.2.2.2. Cognitive engagement. Participants were cognitively engaged in STEM by being strategic. For example, one participant noted:

> It was a really good activity for us to do because it required a lot of thought. First to make sure we built it correctly, and then for the programming it required a lot of thought and focus to say, ‘Okay, this is what we need to do’, ‘This is how we do it, put the chips and this in certain spots.’

Autonomous motivation, as opposed to controlled motivation that would have led to participants' classroom work just to perform required tasks, was also indicated during interviews. For example, one participant reported her voluntary extra work for the sake of joy, “the building part was fun, but l liked the programming part to see how I could do it in different ways, trying to make it either zigzag or different turns it can make, and stuff.”

4.2.2.3. Emotional engagement. Participants were emotionally engaged in STEM. Their *interests* in STEM grew, especially in technology for computer programming, and they *enjoyed* the technology that they were also *frustrated* with. Their initial frustration seemed from a lack of *confidence* in STEM. In fact, many stated that they used to think they were not good at STEM. However, they developed confidence as illustrated in one participant's comment:

> I know. I just get in my head thinking, oh, math and science, I'm not good at those, because I'm a girl, and I can't be good at those. But I learned through this exercise, yes, I am really good at these things that require computers, and working with your hands, and things like that.

Newly developed confidence in computer programming also was often reported: “I still wouldn't say I have a very good grasp of computer programming just from this exercise, but it is easier than I thought it would be.” Participants recognized *value* in STEM. One participant noted, “STEM knowledge really has stuff that kids can use like in real life situations outside of school, rather than just like filling out a test.”

4.3. RQ3: is there any change in participants' STEM learning after participating in robotics activities?

4.3.1. STEM knowledge assessment

A paired t-test was performed to determine whether there was any change in participants' science and technology knowledge after participating in the robotics activities. On engineering and mathematics knowledge, the Wilcoxon Signed-Rank test was performed due to the violation of the normality assumption. To secure power and validity of the analysis, we used the non-parametric method (Pappas & DePuy, 2004). Table 7 shows the results of these analyses. There was no significant change in participants' knowledge of science ($t = 1.496$, $p = 0.155$, $r = 0.14$), technology ($t = 0.097$, $p = 0.924$, $r = 0.01$), engineering ($Z = 0.000$, $p = 1.000$, $r = 0.00$), or mathematics ($Z = -0.1776$, $p = 0.860$, $r = -0.03$).

Table 7
STEM knowledge analysis results.

	Pre-survey (n = 16)		Post-survey (n = 16)				
	Result of Paired Samples t-test						
	M	*SD*	*M*	*SD*	*t*	*p*	*r*
Science Knowledge[a]	8.250	2.176	8.813	1.905	1.496	.155	.14
Technology Knowledge[b]	16.310	3.005	16.37	2.754	0.097	.924	.01
	Result of Wilcoxon Signed-Rank Test						
	M	*SD*	*M*	*SD*	*Z*	*p*	*r*
Engineering Knowledge[c]	10.880	2.217	11.130	1.821	.000	1.000	.00
Mathematics Knowledge[d]	1.50	.730	1.440	.727	−.176	.860	−.03

Note.
[a] Possible range of science knowledge score: 0–16.
[b] Possible range of technology knowledge score: 0–19.
[c] Possible range of engineering knowledge score: 0–14.
[d] Possible range of mathematics knowledge score: 0–3.

4.3.2. *Student interview*

Three themes emerged from interviews on STEM learning: (a) more frequent acknowledgment of learning about science, technology, and engineering than mathematics, (b) a lack of articulation of specific STEM content, and (c) more applications of prior STEM knowledge than new learning.

All but two participants reported that they acquired new STEM knowledge through robotics activities. When they pointed out specific content that they newly acquired, engineering knowledge was the most frequently mentioned. For example, one participant said, “I think that [I learned the] engineering design process. That was new to me.” Technology was often referred to as the new knowledge they acquired from robotics activities, mostly in terms of computer programming but also robots as technology. One participant highlighted the newness of programming, “That whole programming system was new. I've never used anything like that before.” With regard to science, one participant said, “You kind of have to learn about how infrared works to be able to understand because when we were trying to program, we were thinking, ok, do we need to have the infrared system to sense it and then that makes it go, or if it senses nothing, and then doesn't go. We had to think about what that meant.” When it comes to mathematics, one participant reported, “We made ours going like a circle. I guess you can take it as a mathematical process although ours didn't go like the full 360.” Another participant acknowledged her initial lack of STEM knowledge, “I learned a lot … It was frustrating at times then I'm glad we got through it, and we were able to make something. It's really cool to see our end result and just to know that we were able to do something even though we had no knowledge of it coming into the project.”

Some participants articulated less of what they learned in terms of individual subjects. Rather, they explained the process of learning with robots as seamless in relation to STEM. For example, one participant could not even pinpoint the new STEM knowledge she had learned; rather, she noted that her prior STEM knowledge was practiced while participating in robotics activities:

> It's hard for me to say that I didn't learn anything, because like, some of the stuff from the STEM process I knew beforehand, but I felt like it was elaborated more when we were learning about STEM. So I felt like my knowledge of it became better, more than anything just changing.

4.4. *RQ4: How does participating in robotics activities influence participant's STEM teaching?*

4.4.1. *Lesson plan*

Table 8 shows descriptive statistics including means, standard deviations, and the number of lesson plans that met each criterion. The mean of the total scores was 6.13 out of 10.00 and standard deviation was 1.26. Since we scored either 0 (for the criterion that the lesson did not meet) or 1 (for the criterion that the lesson met), the mean of over 0.5 for a criterion indicates that more than half of the lesson plans satisfied the criterion.

4.4.1.1. Inclusion of multiple STEM subjects. Half of the participants included at least one STEM subject in their lesson plans ($M = 0.50$ for *STEM Inclusion*). Science was listed six times, both technology and engineering were listed once, and mathematics was listed twice. Only five participants included more than one subject ($M = 0.31$ for *Multi-subject Inclusion*), four of which included two subjects and one of which included four subjects (science, technology, engineering, and English). Integrative STEM was not observed ($M = 0.00$ for *Integrative STEM Inclusion*).

4.4.1.2. Use of a robot to teach the subject. All participants included a robot in their lessons as a part of the learning materials ($M = 1.00$ for *Robot Inclusion*). However, not all participants *integrated* robots into teaching the subject ($M = 0.81$ for *Robot Integration*). In a lesson in which the *Robot Integration* criterion was not met, for example, English was the subject to be taught

Table 8
Descriptive statistics for lesson plan scores.

Evaluation criteria	Number of lessons that met the criterion among 16	*M*	*SD*
1. Subject Specification	9	0.56	.51
2. Multi-subject Inclusion	5	0.31	.48
3. STEM Inclusion	8	0.50	.52
4. Integrative STEM Inclusion	0	0.00	.00
5. Objectives Specification	12	0.75	.45
6. Standards Specification	15	0.94	.25
7. Activity Description	10	0.63	.50
8. Alignment among Standards/Subject/Activity	10	0.63	.50
9. Robot Inclusion	16	1.00	.00
10. Robot Integration	13	0.81	.40
Total		6.13	1.26

Note: Possible range of each criterion is 0 (the criterion was not met) − 1 (the criterion was met).

but teaching the target audience to build a robot was planned instead of using the robot to teach English content. In contrast, in a lesson in which the *Robot Integration* criterion was met, students programmed their robots to go through a square-shaped path. This lesson was designed to have students observe and assess how their robots move per programming setting, as part of activities teaching a specified a science standard.

4.4.1.3. Technicality and alignment. A majority of participants specified objectives ($M = 0.75$ for *Objective Specification*) and standards ($M = 0.94$ for *Standard Specification*) in their lesson plans and provided a clear description of their lesson activity with sufficient information ($M = 0.63$ for *Activity Description*). In more than a half of lesson plans, standards were aligned with specified subjects and activities ($M = 0.63$ for *Alignment*). For example, in a lesson in which the *Alignment* criterion was met, the activity involved the manipulation of robot parts and testing of robot movements, to meet the standard on exploring scientific and technological matters by changing models and systems. On the other hand, in a lesson in which the *Alignment* criterion was not met, only robot assembly and writing about the robot assembly were included in the lesson activity although the subjects to be taught included not only English but also mathematics.

4.4.2. Student interview

Three themes emerged from interviews on STEM teaching: (a) plans for STEM teaching to provide early exposure of young kids including girls to STEM, (b) plans for using robots for STEM teaching, and (c) robots as a tool to prepare their STEM teaching. First, participants shared their plans as a teacher to *expose STEM to young kids* because of the importance of learning about STEM early. One participant noted, “If it [STEM learning] starts in elementary, then it can build in middle school and high school and in college. And then maybe more people would be attracted to the STEM majors and professions.” Another participant explained that early exposure would lead to further education opportunities that are otherwise impossible, “[You can learn] like the whole programing experience, doing something new that you've never done before and how that can enhance or further your education in different areas that you might not be thinking about.” Participants also highlighted their future STEM teaching to *girls* so that more females would consider a future career in an STEM field. One participant said, “It's great to expose them to that [STEM], especially the girls because that is such a male-dominated field. So I think it's really good for girls to explore that.” However, a few participants limited the scope of the exposure only to a shallow level:

> I think it's important to be introduced in elementary school, maybe not like go really in-depth with it [STEM], because the younger kids might not really understand it much. But having an introduction to it, then they have a little bit of experience with it, then they can carry that into their later use, like middle school, high school, or even college when they start to look at STEM and understand what it actually is. A little instruction is definitely good.

Second, participants planned to use *robots* for teaching STEM because of benefits of learning STEM via robots, as long as the school affords and allows teaching with robots. Participants emphasized that STEM knowledge could be taught *through* robotics. One participant stated, “I think the robotics would be kind of unrelated subject without STEM. You could teach in the classroom, but it would kind of be just a fun activity. It wouldn't be necessarily educationally related.” Their plan to use robots for STEM teaching, however, was not just for STEM content learning but also for *learning the processes of learning* such as communications, collaborations, and critical thinking, as illustrated in the following comment:

> As a future teacher, it helps you see, when you get frustrated with the situation, you just need to take a step back for a minute, rethink it and then go back to it. Most of it was not specifically math, technology things. It was more like overall critical thinking skills and learning how to relate advanced technology back to a classroom of younger kids. It might not be specific standards we learned. But it was like overall things that would help in the future when you are doing other stuff.

Nonetheless, a few participants noted that they would have to learn more about how to better use robots with younger students. One participant commented, “I would like to learn what kind of thing you could do with really younger graders, not necessarily the exact activity we did.” Another participant expressed her concern about younger students' capability with robot assembly:

> If I had little kids, I would certainly try to incorporate a lesson with demonstrations, but I don't think I will have them construct anything. Some of the pieces are kind of hard to fit together, requiring a little strength to get them to go together. So I don't think little kids would be able to do that.

Last, participants also highlighted robots as a tool to prepare their teaching as one participant noted:

> It [the robotics activity] required a lot of thought and focus. It was good for us to think about how we can incorporate other activities in our classroom. We might not have thought to do that without this activity. Honestly, I would never have thought about incorporating robotics in my classroom before this activity.

Preparation for their STEM teaching via robotics was mentioned also. For example, one participant underlined the need to learn more about STEM in order to teach STEM with robots, in the following comment:

> I think it's really important to understand STEM because if you don't really understand the science, or technology, or engineering, or math behind it [robotics], then you can't really like robotics. I think it's important to understand STEM so that you can teach robotics. I can look at the workbook and assemble this robot and look at the programming with a little bit of help with those things without really knowing what STEM is. But, in order to teach it, I think it is important to know what it is, and how it relates to what you did, so that younger kids can understand that too.

5. Discussion

5.1. Summary of findings and interpretation

Both quantitative and qualitative data analyses indicated that pre-service teachers engaged in robotics activities actively and mindfully. Their STEM engagement improved overall. Interestingly, the change in their STEM knowledge did not contribute to the change in their STEM engagement, statistically. Rather, their emotional engagement (e.g., interest, enjoyment) in STEM significantly increased and in turn seemed to have influenced their behavioral and cognitive engagement in STEM. Their lesson designs showed that their STEM teaching was developing in productive directions although further work was needed. These findings suggest that robotics can be used as a technology to enhance teachers' STEM engagement and teaching through improving affective reactions to STEM. Details of the study findings are discussed in the following sections.

5.1.1. Engagement in robotics activities

Overall, pre-service teachers exhibited active engagement in robotics activities. Their behavioral engagement was noticeable in that *all* were involved in the activities and that little behavioral disaffection was observed. For example, a distracted behavior appeared only once during robot assembly. During the interview, they reported that they were immersed in robotics activities. Such active engagement can be attributed to their hands-on work with assembly and programming, something that has been reported in prior studies as part of the motivating nature of robotics (Matarić et al., 2007; Nugent et al., 2010; Osborne et al., 2010). For example, in a study of teaching programming through robotics, first-year undergraduate engineering students fully engaged in “hands-on programming using target hardware” and even preferred it to pure programing (Collier, Duran, & Ordys, 2012, p. 128). In fact, positive comments were often made on the hands-on aspect of robotics activities during interviews in the current study.

We observed that pre-service teachers worked even harder when encountering difficulties. All pre-service teachers experienced difficulties, but managed them through trial and error as well as seeking help from peers or the instructor. These strategic actions exemplify cognitive engagement (Fredricks et al., 2004) that was also evidenced in the current study by classroom observations of exchanging ideas, questioning, and answering questions in collaborative small groups and with the instructor (Helme & Clarke, 2001). Finding a solution to overcome difficulties involves a problem-solving process. One way of using robotics in education is in a problem-solving approach (Altin & Pedaste, 2013). In the current study, many participants noted robotics activities led to their problem solving through critical thinking, reflection, and trial and error. This finding illustrates the benefits of learning with robotics for teacher preparation. Teaching requires problem-solving (Hsu, 2004). In addition, experience and knowledge of how to persist through difficulties is important to achieve goals (Kim & Bennekin, 2013) including the goal of effective teaching.

Pre-service teachers' regulation of negative emotions appeared to be a critical part of their engagement in robotics activities considering that many followed a path from frustration to enjoyment. Frustration was from a lack of prior experience and confidence in STEM as stated by many pre-service teachers. However, seeing others' frustration may have helped them regulate their emotion of frustration since social interactions are critical in one's emotional experience (Gross, 2002). Frustration may also have been a motivator for active, mindful engagement. Research shows that negative emotions, such as anxiety (Carrier, Higson, Klimoski, & Peterson, 1984), facilitate learning. However, to be resilient from negative emotional experience, “a sense of self-competence” is required (Turner & Schallert, 2001, p. 327). Thus, the transition from pre-service teachers' emotions of frustration to enjoyment recorded in the current study, despite their lack of prior knowledge and confidence in robotics, is a crucial piece of the positive impact of robotics activities.

5.1.2. STEM engagement

While participating in robotics activities, pre-service teachers' emotional engagement (i.e., interests and enjoyment) in STEM improved overall. Their interest in *engineering* significantly increased, with a medium effect (see Table 6). This is an important finding since engineering is generally “the often-neglected component of STEM education” (DiFrancesca et al., 2014, p. 50). Pre-service teachers' interest in engineering is critical in their future STEM education, especially in primary schools where STEM education tends to be weak (Hossain & Robinson, 2012). We infer that the increase in their interests in engineering came from the engineering design process during robot building and programming that pre-service teachers often referred to during interviews. In prior research, the use of robotics engaged kindergarten kids in the engineering design process (Bers, 2010), led to middle school students' development of engineering design skills (Larkins et al., 2013), and allowed even engineering students to experience a “real engineering design process” (Bers & Portsmore, 2005, p. 68).

Pre-service teachers' interest in *science* increased as well with a statistically significant medium effect. The use of robotics in science education is not new (Altin & Pedaste, 2013). However, training teachers, especially early childhood education teachers, to use robotics for science teaching is not common (c.f., Bers & Portsmore, 2005). Moreover, robotics in the current study for getting elementary pre-service teachers *interested* in science is, to our knowledge, unprecedented. One recent study (Araújo, Burlamaqui, & Aroca, 2013) examined pre-service teachers' interests in teaching physics (e.g., distance and displacement) using robotics but they were already interested in science as demonstrated by their taking the physics class in which the study was conducted. The findings on interests are noteworthy in that many pre-service teachers in the current study initially defined themselves as lacking in STEM subject areas.

Although the increase was not statistically significant, pre-service teachers' interests in *technology* grew as well. Their newly developed interest in technology in the form of programming was frequently highlighted during interviews. Their emotional engagement in technology was present in that they were scared of, overwhelmed with, and frustrated with, and then enjoyed it. Also, an increasing trend of their interest in *STEM careers* was noteworthy considering that their career goals were already set to become an early childhood educator.

Pre-service teachers' *enjoyment* in STEM-related topics and coursework increased after participating in robotics activities, with a statistically significant small effect. During interviews, “I enjoyed,” was frequently said. Their *autonomous motivation*, indicating a high level of cognitive engagement, improved as well with a statistically significant medium effect (see Table 6). These findings are consistent with the literature on the interrelatedness of emotions and motivation (e.g., Kim & Pekrun, 2014) especially showing interests and enjoyment that impact autonomous motivation and vice versa (e.g., Mouratidis, Vansteenkiste, Sideridis, & Lens, 2011).

Pre-service teachers used metacognitive strategies while engaged in STEM, particularly engineering (building) and technology (programming). This finding may have resulted from “robotics-based learning in a complex and chaotic environment needed for the use of problem-solving skills and critical thinking” (Blanchard, Freiman, & Lirrete-Pitre, 2010, p. 2856). Critical thinking observed from the current study is aligned with findings from prior research indicating that the use of robotics can lead to improvement in critical thinking skills (Bers, 2008). This benefit was not targeted intentionally in previous studies of teacher education using robotics.

Pre-service teachers were fully engaged in STEM. Many reported that there was no conscious effort in staying engaged in STEM per se. Rather, their STEM engagement was rather seamless because STEM was presented not with the label of STEM but through robotics.

A decrease was observed in pre-service teachers' interest in mathematics although the change was not statistically significant. During interviews, only a few pointed out specific mathematics-related experiences. Mathematical thinking and concepts are taught through robotics (Olive et al., 2010). However, it is difficult to maintain learners' interests in mathematics through robotics after the initial attention to the technology (Silk, Higashi, Shoop, & Schunn, 2009). No positive impact on interest in mathematics may be related to the seamless engagement discussed earlier. Without explicit mathematical thinking and concepts identified during robotics activities, pre-service teachers may have not realized parts of the activities that were mathematics-related and interesting to them. Model-eliciting can be integrated into robotics activities (Silk et al., 2009). Through model-eliciting, learners can become more cognizant of mathematical problem solving processes (Moore & Carlson, 2012). Model-eliciting is effective in mathematics learning especially involving engineering (Hamilton, Lesh, Lester, & Brilleslyper, 2008).

5.1.3. STEM learning

Pre- and post-surveys assessing pre-service teachers' STEM knowledge revealed that there was no statistically significant change after their participation in robotics activities. This finding is discrepant from interview findings in that all but two pre-service teachers reported on their newly acquired STEM knowledge. However, the kind of STEM knowledge reported during interviews appeared distinct from that of the STEM knowledge assessed using the surveys. During interviews, STEM knowledge was always referred to within the scope of robotics. For example, when one pre-service teacher talked about mathematics knowledge, she talked about calculation of degrees for programming a robot to travel in a circle. On surveys, some questions were relevant to robotics activities; for example, knowledge of how to calculate a distance between different locations on a map using a grid could be learned while programming a robot to move a certain direction and distance. However, many other questions seem inapplicable to robotics activities in the current study, such as, “A large tree is struck by lightning and it comes crashing down. What will happen to that dead tree after 100 years?” (Sadler et al., 2006).

In general, specific STEM knowledge, other than robot building and programming, is not taught for teacher professional development on robotics; rather, the *application* of STEM knowledge is learned (e.g., Sullivan & Moriarty, 2009). For example, teachers are assumed capable of calculating speed that is applied to robot programming. Considering this was the case in robotics-related courses for pre-service teachers in the current and prior studies (e.g., Bers & Portsmore, 2005), it may have been more logical if the impact of robotics on STEM learning was examined in surveys in terms of *application* of STEM knowledge to robot building and programming as well as teaching with robotics. In fact, in a study of professional development on educational robotics (Sullivan & Moriarty, 2009), the researchers assessed teachers' knowledge required for teaching with robotics (e.g., “robotics and science inquiry”, p. 140).

It is also possible that there could have been different effects of robotics activities on pre-service teachers' STEM learning depending on their initial knowledge level. Although we could not perform a further analysis to examine this possibility due to the small sample size, in prior research using robotics in middle school classrooms (Lindh & Holgersson, 2007), knowledge gain was not different between the experimental and control groups overall but average performers in the experimental group showed statistically significantly higher gain in mathematics knowledge than those in the control group.

Nonetheless, it is interesting to see an increasing trend in pre-service teachers' knowledge of science, technology, and engineering but not in that of mathematics. This is more consistent with findings from interviews in which only three pre-service teachers mentioned mathematics when talking about new STEM learning. Although unclear, less attention to mathematics might have been related to the observation that interest in mathematics is closely associated with mathematics learning in general (Conard & Marsh, 2014). As seamless engagement was discussed earlier, this finding may be from the seamless process of using mathematical knowledge in robotics activities. If preservice teachers were reminded that the fun they had with robot building and programming was related to mathematical thinking and concepts, their interests in and learning of mathematics may have been different. Along these lines, explicit STEM integration may be needed, especially in mathematics, although this need should be confirmed through an experimental study with a larger sample size. Specifically targeted STEM content was integrated into teaching pre-service teachers how to teach the content with robots, for example, speed and velocity in physics (Araújo et al., 2013). Seamless learning of STEM through robotics that incorporates reflective thinking (Dewey, 1933) about explicit STEM learning (Abramovich, 2012) may be needed for pre-service teachers. This could help them determine what of STEM they can and should integrate into their future teaching with robots to guide their future students' seamless learning of STEM.

5.1.4. STEM teaching

All pre-service teachers planned to use robots in their lessons (see Table 8). More than 80% of the pre-service teachers designed lesson materials that would *integrate* robots into teaching. Their use of robots was not just including the technology but integrating it into teaching target content. Technology integration is difficult even for many in-service teachers (Belland, 2009). Technology integration implies that technology is used not as “an add-on instrument” but as “a critical element” for student learning (Lee & Kim, 2014, p. 438). However, 20% listed robots as their instructional material without connecting the technology to the content and pedagogy in the lesson. Also, the alignment among objectives, standards, and activities was found in only about 60% of lessons.

Pre-service teachers in the current study were not required to design a lesson that would specifically focus on STEM content. They had autonomy to choose any subject, objective, and standard. However, 50% did plan to teach at least one of the STEM subjects. Even those who did not do so mentioned during interviews that they would like to use robots in their future STEM teaching. However, only about 25% included two subjects and no one designed a lesson teaching all content areas of STEM. Integrative STEM education, despite its importance, is a persistent challenge in education (Nadelson & Seifert, 2013). For pre-service teachers, their limited conception of teaching (Ford, Fifield, Madsen, & Qian, 2013) may have impacted their choice of topics for lesson plans although they knew their future job would require them to teach multiple subjects as an elementary teacher. It is also possible that their classroom experience as students is not aligned with the anticipated role as an elementary teacher (Ford et al., 2013). Their lack of mathematics interest and knowledge, as discussed earlier, may have influenced their decision on subjects. Among the sixteen lesson plans, mathematics was listed only twice. One lesson teaching four subjects included science, technology, engineering, and English.

It is noteworthy that most pre-service teachers stated during interviews that they would like to expose STEM to young kids and girls. They valued their robotics experience, reflected on their own early childhood learning opportunities, and perceived the importance of STEM education at the elementary level. However, the exposure seemed only at a shallow level. To maximize the positive impact of robotics experience on teaching, especially integrative teaching of STEM for young children, observational learning can be implemented in future studies. How these pre-service teachers learn STEM is critical for how they will teach their students STEM (Kagan, 1992). Observational learning refers to “learning by observing other persons' behavior (i.e., models)” (Renkl, 2014, p. 8). Observational learning was effective in numerous studies (e.g., Bjerrum, Hilberg, Gog, Charles, & Eika, 2013). Providing the opportunity to observe others' integration of STEM in robotics activities as a model may help with their lesson design.

Last but not least, pre-service teachers viewed robotics as a tool to prepare their STEM teaching. Frustration, which was from discovery learning with robotics, led to concern among teachers in prior research on professional development with robotics (Sullivan & Moriarty, 2009). However, in the current study, no pre-service teacher's remarks on their frustration was negative. It was rather positive in that it helped to highlight their unexpectedly positive experience with robotics. No one indicated during interviews and in lesson designs that they would try to reduce their students' frustration. This may be from their naïve conception of teaching, without full understanding of what teaching is, compared to in-service teachers in Sullivan and Moriarty's study (2009). Nonetheless, they considered robotics activities a great way to develop themselves as effective STEM teachers.

Only a couple of lessons in the current study were for student learning *from* technology rather than learning *with* technology (Jonassen, Peck, & Wilson, 1999). Teachers exhibited different levels of proficiency with technology integration even after extensive professional development in prior research (Kim et al., 2013). Although constructivist ways of teaching were a focus of neither robotics activities nor the course, a student-centered approach in which they were allowed to learn *with* technology (i.e., robots) may have influenced, as a model of teaching, how these two pre-service teachers' designed their lesson plans. Future research could consider an investigation of what may have influenced this level of quality in lessons developed by relatively inexperienced pre-service teachers.

5.2. Limitations of the study and future research directions

Several limitations were present in the study reported here. First, there was no control group so the internal validity of the study is limited (Shadish, Cook, & Campbell, 2002). Second, the generalizability of the study results is limited due to a small number of participants. A quasi-experimental study with a larger number of participants should be considered in the future. Third, there was a wide range of reliability of the instruments used for pre- and post-surveys (see the Data Collection section). This may have led to the discrepancy between the quantitative and qualitative data. Last, STEM teaching was assessed through evaluating participants' lesson plans, rather than their actual teaching of students. Future research should consider a follow-up study of participant's actual teaching as a student teacher or as an in-service teacher to assess STEM teaching by evaluating the implementation of a lesson rather than just its design.

Still, there could be many difficulties implementing robotics lessons in classrooms. In a study of Barker et al. (2014), not all teachers implemented what they were supposed to do based on their training for teaching with robots. The researchers attributed this outcome to a lack of teacher efficacy and informal characteristics of summer camps. In fact, difficulties with monitoring and facilitating (Jormanainen, Zhang, Kinshuk, & Sutinen, 2007) could lower teacher efficacy and thus future research should also take contextual factors into consideration for optimal implementations in actual classrooms.

5.3. Implications of the study for research on STEM learning and Teacher education

Multiple data sources allowed an in-depth understanding of the potential impact of educational robotics on teacher training and STEM education. In addition, the research-based design of the study investigating engagement can provide guidance for future research that would examine the impact of teacher education on STEM learning and teaching. This study also showcased the productive learning that can occur when transforming negative emotions to positive emotions.

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References

Abramovich, S. (2012). Collateral learning and mathematical education of teachers. *International Journal of Mathematical Education in Science & Technology, 43*(3), 315–336. http://doi.org/10.1080/0020739X.2011.618551.

Adams, A. E., Miller, B. G., Saul, M., & Pegg, J. (2014). Supporting elementary pre-service teachers to teach STEM through place-based teaching and learning experiences. *Electronic Journal of Science Education, 18*(5), 1–22.

Alimisis, D. (2013). Educational robotics: open questions and new challenges. *Themes in Science & Technology Education, 6*(1), 63–71.

Alimisis, D., Moro, M., Arlegui, J., Pina, A., Frangou, S., & Papanikolaou, K. (2007). Robostics & constructivism in education: the TERECoP project. In *Proceedings of the 11th European Logo Conference. Comenius University, Bratislava*.

Altin, H., & Pedaste, M. (2013). Learning approaches to applying robotics in science education. *Journal of Baltic Science Education, 12*(3), 365–377.

Araújo, A. R., Burlamaqui, A. M. F., & Aroca, R. V. (2013). Methodology for qualification of future teachers in physics' degree course using low cost robotics. In *2013 Latin American Robotics Symposium & Competition* (pp. 148–152).

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2013). "Not girly, not sexy, not glamorous": primary school girls' and parents' constructions of science aspirations. *Pedagogy, Culture & Society, 21*(1), 171–194. http://doi.org/10.1080/14681366.2012.748676.

Arlegui, J., Pina, A., & Moro, M. (2013). A PBL approach using virtual and real robots (with BYOB and LEGO NXT) to teaching learning key competences and standard curricula in primary level. In *Proceedings of the First International Conference on Technological Ecosystem for Enhancing Multiculturality* (pp. 323–328). New York, NY, USA: ACM. http://doi.org/10.1145/2536536.2536585.

Barker, B. S., Grandgenett, N., Nugent, G., & Adamchuk, V. I. (2010). Robots, GPS/GIS, and programming technologies: the power of "digital manipulatives" in youth extension experiences. *Journal of Extension, 48*(1), 1–9.

Barker, B. S., Nugent, G., & Grandgenett, N. (2008). Examining 4-H robotics and geospatial technologies in the learning of science, technology, engineering, and mathematics topics. *Journal of Extension, 46*(3), 22–22.

Barker, B. S., Nugent, G., & Grandgenett, N. (2014). Examining fidelity of program implementation in a STEM-oriented out-of-school setting. *International Journal of Technology & Design Education, 24*(1), 39–52. http://doi.org/10.1007/s10798-013-9245-9.

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.

Beer, R. D., Chiel, H. J., & Drushel, R. F. (1999). Using autonomous robotics to teach science and engineering. *ACM, 42*(6), 85–92. http://doi.org/10.1145/303849.303866.

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. http://doi.org/10.1016/j.compedu.2008.09.004.

Bers, M. U. (2008). *Blocks to robots: Learning with technology in the early childhood classroom*. New York, NY: Teachers College Press.

Bers, M. U. (2010). The tangibleK robotics program: applied computational thinking for young children. *Early Childhood Research & Practice, 12*(2). Retrieved from http://files.eric.ed.gov/fulltext/EJ910910.pdf.

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

Bjerrum, A. S., Hilberg, O., van Gog, T., Charles, P., & Eika, B. (2013). Effects of modelling examples in complex procedural skills training: a randomised study. *Medical Education, 47*(9), 888–898. http://doi.org/10.1111/medu.12199.

Black, A. E., & Deci, E. L. (2000). The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: a self-determination theory perspective. *Science Education, 84*(6), 740–756.

Blanchard, S., Freiman, V., & Lirrete-Pitre, N. (2010). Strategies used by elementary schoolchildren solving robotics-based complex tasks: Innovative potential of technology. *Innovation and Creativity in Education, 2*(2), 2851–2857. http://doi.org/10.1016/j.sbspro.2010.03.427.

Bucher, A. M. (2009). A survey of instruments to assess teacher content knowledge in science. Retrieved from https://etd.ohiolink.edu/.

Carrier, C., Higson, V., Klimoski, V., & Peterson, E. (1984). The effects of facilitative and debilitative achievement anxiety on note taking. *The Journal of Educational Research*, (3), 133.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: a theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175–218.

Clark, L. A., & Watson, D. (1995). Constructing validity: basic issues in objective scale development. *Psychological Assessment, 7*(3), 309–319. http://doi.org/10.1037/1040-3590.7.3.309.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155–159. http://doi.org/10.1037/0033-2909.112.1.155.

Collier, G., Duran, O., & Ordys, A. (2012). Technology-centred teaching methods to introduce programming and robotic concepts. *International Journal of Technology, Knowledge & Society, 8*(6), 121–129.

Conard, M. A., & Marsh, R. F. (2014). Interest level improves learning but does not moderate the effects of interruptions: an experiment using simultaneous multitasking. *Learning and Individual Differences, 30*, 112–117. http://doi.org/10.1016/j.lindif.2013.11.004.

Cortina, J. M. (1993). What is coefficient alpha? An examination of theory and applications. *Journal of Applied Psychology, 78*(1), 98–104. http://doi.org/10.1037/0021-9010.78.1.98.

Coxon, S. V. (2012). The malleability of spatial ability under treatment of a FIRST LEGO League-based robotics simulation. *Journal for the Education of the Gifted, 35*(3), 291–316.

Creswell, J. W., & Clark, V. L. P. (2007). *Designing and conducting mixed methods research*. Thousand Oaks, CA: Sage.

Creswell, J. W., Clark, V. L. P., & Gutmann, M. (2003). Advanced mixed method research designs. In A. Tashakkori, & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 209–240). Thousand Oaks, CA: Sage.

Cunningham, C. M. (2009). Engineering is elementary. *The Bridge, 30*(3), 11–17.

Dewey, J. (1933). *How we think: a restatement of the relation of reflective thinking to the educative process*. Boston, New York [etc.] D.C.: Heath and Company.

DiFrancesca, D., Lee, C., & McIntyre, E. (2014). Where is the “E” in STEM for young children? *Issues in Teacher Education, 23*(1), 49–64.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). *Taking science to school: Learning and teaching science in grades K-8* (p. c2007). Washington, D.C.: National Academies Press. Retrieved from http://books.nap.edu/openbook.php?record_id=11625&page=1.

Field, A. P. (2009). *Discovering statistics using SPSS* (p. c2009). Los Angeles; London: SAGE.

Finn, J., & Zimmer, K. (2012). Student engagement: what is it? why does it matter? In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 97–131) Springer US. Retrieved from http://dx.doi.org/10.1007/978-1-4614-2018-7_5.

Fisher, D., & Frey, N. (2009). *Background knowledge: The missing piece of the comprehension puzzle*. Portsmouth, NH: Heinemann.

Ford, D., Fifield, S., Madsen, J., & Qian, X. (2013). The science semester: cross-disciplinary inquiry for prospective elementary teachers. *Journal of Science Teacher Education, 24*(6), 1049–1072. http://doi.org/10.1007/s10972-012-9326-8.

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.

Fredricks, J. A., & McColskey, W. (2012). The measurement of student engagement: a comparative analysis of various methods and student self-report instruments. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 763–782). Springer US. Retrieved from http://dx.doi.org/10.1007/978-1-4614-2018-7_37.

Gibbons, J. D., & Chakraborti, S. (2011). *Nonparametric statistical inference* (5th ed.). Boca Raton, FL: Taylor & Francis Group, LLC.

Goldman, R., Eguchi, A., & Sklar, E. (2004). Using educational robotics to engage inner-city students with technology. In Y. B. Kafai (Ed.), *Proceedings of the 6th International Conference on learning Sciences* (pp. 214–221). Santa Monica, CA: Mahwah: Lawrence Erlbaum.

Greenberg, J., McKee, A., & Walsh, K. (2013). *Teacher prep review 2013 report. National Council on Teacher Quality*. Retrieved from http://www.nctq.org/dmsView/Teacher_Prep_Review_2013_Report.

Gross, J. J. (2002). Emotion regulation: affective, cognitive, and social consequences. *Psychophysiology, 39*(3), 281–291.

Hamilton, E., Lesh, R., Lester, F., & Brilleslyper, M. (2008). Model-Eliciting Activities (MEAs) as a bridge between engineering education research and mathematics education research. *Advances in Engineering Education, 1*(2), 1–25.

Helme, S., & Clarke, D. (2001). Identifying cognitive engagement in the mathematics classroom. *Mathematics Education Research Journal, 13*(2), 133–153. http://doi.org/10.1007/BF03217103.

Hossain, M. M., & Robinson, M. G. (2012). *How to motivate US students to pursue STEM (Science, Technology, Engineering and Mathematics) careers* (pp. 442–451). US-China Education Review.

Hsu, S. (2004). Using case discussion on the web to develop student teacher problem solving skills. *Teaching and Teacher Education, 20*(7), 681–692. http://doi.org/10.1016/j.tate.2004.07.001.

Jonassen, D. H., Peck, K. L., & Wilson, B. G. (1999). *Learning with technology: A constructivist perspective*. Upper Saddle River, N.J.: Merrill. c1999.

Jormanainen, I., Zhang, Y., Kinshuk, & Sutinen, E. (2007). *Pedagogical agents for teacher intervention in educational robotics classes: Implementation issues* (pp. 49–56). Jhongil, Taiwan: IEEE. http://doi.org/10.1109/DIGITEL.2007.38.

Kagan, D. M. (1992). Professional growth among preservice and beginning teachers. *Review of Educational Research, 62*(2), 129–169. http://doi.org/10.2307/1170578.

Karahoca, D., Karahoca, A., & Uzunboylub, H. (2011). Robotics teaching in primary school education by project based learning for supporting science and technology courses. *World Conference on Information Technology, 3*, 1425–1431. http://doi.org/10.1016/j.procs.2011.01.025.

Kay, J. S., Moss, J. G., Engelman, S., & McKlin, T. (2014). Sneaking in through the back door: Introducing K-12 teachers to robot programming. In *Proceedings of the 45th ACM Technical Symposium on Computer Science Education* (pp. 499–504). New York, NY, USA: ACM. http://doi.org/10.1145/2538862.2538972.

Kazakoff, E., Sullivan, A., & Bers, M. (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. http://doi.org/10.1007/s10643-012-0554-5.

Kim, C., & Bennekin, K. N. (2013). Design and implementation of volitional control support in mathematics courses. *Educational Technology Research & Development, 61*(5), 793–817. http://doi.org/10.1007/s11423-013-9309-2.

Kim, C., Kim, M. K., Lee, C., Spector, J. M., & DeMeester, K. (2013). Teacher beliefs and technology integration. *Teaching and Teacher Education, 29*(0), 76–85. http://doi.org/10.1016/j.tate.2012.08.005.

Kim, C., & Pekrun, R. (2014). Emotions and motivation in learning and performance. In J. M. Spector, M. D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of research on educational communications and technology* (4th ed., pp. 65–75). New York, NY: Springer New York.

Knowledge of Algebra for Teaching Project Group. (2009). *Interpretation of Knowledge of Algebra for Teaching (KAT) IRT scale scores*. Michigan State University.

Larkins, D. B., Moore, J. C., Rubbo, L. J., & Covington, L. R. (2013). Application of the cognitive apprenticeship framework to a middle school robotics camp. In *Proceeding of the 44th ACM Technical Symposium on Computer Science Education* (pp. 89–94). New York, NY, USA: ACM. http://doi.org/10.1145/2445196.2445226.

Lee, C.-J., & Kim, C. (2014). An implementation study of a TPACK-based instructional design model in a technology integration course. *Educational Technology Research and Development, 62*(4), 437–460. http://doi.org/10.1007/s11423-014-9335-8.

Lindh, J., & Holgersson, T. (2007). Does Lego training stimulate pupils' ability to solve logical problems? *Computers & Education, 49*(4), 1097–1111.

Mahatmya, D., Lohman, B. J., Matjasko, J. L., & Farb, A. F. (2012). *Engagement across developmental periods. Handbook of Research on Student Engagement* (p. 45).

Maltese, A. V., & Tai, R. H. (2010). Eyeballs in the fridge: sources of early interest in science. *International Journal of Science Education, 32*(5), 669–685. http://doi.org/10.1080/09500690902792385.

Martin, A. (2012). Part II Commentary: motivation and engagement: conceptual, operational, and empirical clarity. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of Research on Student Engagement* (pp. 303–311). Springer US.

Matarić, M. J., Koenig, N., & Feil-Seifer, D. (2007). Materials for enabling hands-on robotics and STEM education. In *Proceedings of AAAI Spring Symposium on robots and Robot Venues: Resources for AI Education*. Stanford, CA: American Association for Artificial Intelligence (AAAI).

McGill, M. M. (2012). Learning to program with personal robots: Influences on student motivation. *ACM Transactions on Computing Education, 12*(1).

Mitnik, R., Recabarren, M., Nussbaum, M., & Soto, A. (2009). Collaborative robotic instruction: a graph teaching experience. *Computers & Education, 53*(2), 330–342. http://doi.org/10.1016/j.compedu.2009.02.010.

Moore, K. C., & Carlson, M. P. (2012). Students' images of problem contexts when solving applied problems. *Journal of Mathematical Behavior, 31*(1), 48–59. http://doi.org/10.1016/j.jmathb.2011.09.001.

Mouratidis, A. A., Vansteenkiste, M., Sideridis, G., & Lens, W. (2011). Vitality and interest–enjoyment as a function of class-to-class variation in need-supportive teaching and pupils' autonomous motivation. *Journal of Educational Psychology, 103*(2), 353–366. http://doi.org/10.1037/a0022773.

Murphy, T. P., & Mancini-Samuelson, G. J. (2012). Graduating STEM competent and confident teachers: the creation of a STEM certificate for elementary education majors. *Journal of College Science Teaching, 42*(2), 18–23.

Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: Inquiry-based STEM professional development for elementary teachers. *Journal of Educational Research, 106*(2), 157–168.

Nadelson, L. S., & Seifert, A. (2013). Perceptions, engagement, and practices of teachers seeking professional development in place-based integrated STEM. *Teacher Education & Practice, 26*(2), 242–265.

Nugent, G., Bradley, 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.

Olive, J., Makar, K., Hoyos, V., Kor, L. K., Kosheleva, O., & Sträßer, R. (2010). Mathematical knowledge and practices resulting from access to digital technologies. In C. Hoyles, & J.-B. Lagrange (Eds.), *Mathematics Education and Technology-Rethinking the Terrain* (pp. 133–177). Springer US. Retrieved from http://link.springer.com/chapter/10.1007/978-1-4419-0146-0_8.

Osborne, R. B., Thomas, A. J., & Forbes, J. (2010). Teaching with robots: a service-learning approach to mentor training. In *Proceedings of the 41st ACM Technical Symposium on Computer Science Education* (pp. 172–176). New York, NY: Association for Computing Machinery (ACM).

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books, c1980.

Pappas, P. A., & DePuy, V. (2004). *An overview of non-parametric tests in SAS®: When, Why, and How. Duke Clinical Research Institute*. Durham: North Carolina. Retrieved from http://analytics.ncsu.edu/sesug/2004/TU04-Pappas.pdf.

Pekrun, R., Goetz, T., & Frenzel, A. C. (2007). *Achievement Emotions Questionnaire-Mathematics (AEQ-M): User's manual*. Munich, Germany: Department of Psychology, University of Munich.

Perritt, D. C. (2010). Including professional practice in professional development while improving middle school teaching in math. *National Teacher Education Journal, 3*(3), 73–76.

Petre, M., & Price, B. (2004). Using robotics to motivate "back door" learning. *Education and Information Technologies, 9*(2), 147–158. EAIT.0000027927.78380.60 http://doi.org/10.1023/B.

Pittí, K., Curto, B., Moreno, V., & Rodríguez, M. J. (2013). Resources and features of robotics learning environments (RLEs) in Spain and Latin America. In *Proceedings of the First International Conference on Technological Ecosystem for Enhancing Multiculturality* (pp. 315–322). New York, NY, USA: ACM. http://doi.org/10.1145/2536536.2536584.

Renkl, A. (2014). Toward an instructionally oriented theory of example-based learning. *Cognitive Science, 38*(1), 1–37. http://doi.org/10.1111/cogs.12086.

Reschly, A., & Christenson, S. (2012). Jingle, jangle, and conceptual haziness: evolution and future directions of the engagement construct. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 3–19). Springer US. Retrieved from http://dx.doi.org/10.1007/978-1-4614-2018-7_1.

Ruona, W. E. A. (2005). Analyzing qualitative data. In R. A. Swanson, & E. F. Holton (Eds.), *Research in organizations: Foundations and methods of inquiry* (pp. 223–263). San Francisco, CA: Berrett-Koehler.

Sadler, P. M., Coyle, H. P., Cook-Smith, N., & Miller, J. L. (2006). *MOSART: Misconceptions-Oriented Standards-based Assessment Resources for Teachers*. Cambridge, MA: Harvard College. Retrieved from http://www.cfa.harvard.edu/smgphp/mosart.

Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Boston, MA: Houghton Mifflin.

Silk, E. M., Higashi, R., Shoop, R., & Schunn, C. D. (2009). Designing technology activities that teach mathematics. *Technology Teacher, 69*(4), 21–27.

Skinner, E. A., Kindermann, T. A., & Furrer, C. J. (2008). A motivational perspective on engagement and disaffection: conceptualization and assessment of children's behavioral and emotional participation in academic activities in the classroom. *Educational and Psychological Measurement*. http://doi.org/10.1177/0013164408323233.

Sullivan, F. R., & Moriarty, M. A. (2009). Robotics and discovery Learning: pedagogical beliefs, teacher practice, and technology integration. *Journal of Technology and Teacher Education, 17*(1), 109–142.

Tocháček, D., & Lapeš, J. (2012). The project of integration the educational robotics into the training programme of future ICT teachers. *International Conference on Education & Educational Psychology (ICEEPSY 2012), 69*(0), 595–599. http://doi.org/10.1016/j.sbspro.2012.11.451.

Turner, J. E., & Schallert, D. L. (2001). Expectancy–value relationships of shame reactions and shame resiliency. *Journal of Educational Psychology, 93*(2), 320–329. http://doi.org/10.1037/0022-0663.93.2.320.

Tyler-Wood, T., Knezek, G., & Christensen, R. (2010). Instruments for assessing interest in STEM content and careers. *Journal of Technology and Teacher Education, 18*(2), 341–363.

Williams, G. C., & Deci, E. L. (1996). Internalization of biopsychosocial values by medical students: a test of self-determination theory. *Journal of Personality and Social Psychology, 70*, 767–779.

Williams, D. C., Ma, Y., Prejean, L., Ford, M. J., & Lai, G. (2007). Acquisition of physics content knowledge and scientific inquiry skills in a robotics summer camp. *Journal of Research on Technology in Education, 40*(2), 201–216.

Windschitl, M. (2004). Folk theories of "inquiry:" how preservice teachers reproduce the discourse and practices of an atheoretical scientific method. *Journal of Research in Science Teaching, 41*(5), 481–512.