TechTrends
https://doi.org/10.1007/s11528-019-00388-0

ORIGINAL PAPER

Elementary School Student Development of STEM Attitudes and Perceived Learning in a STEM Integrated Robotics Curriculum

Yu-Hui Ching[1] · Dazhi Yang[1] · Sasha Wang[2] · Youngkyun Baek[1] · Steve Swanson[3] · Bhaskar Chittoori[4]

Abstract
Robotics has been advocated as an emerging approach to engaging K-12 students in learning science, technology, engineering, and mathematics (STEM). This study examined the impacts of a project-based STEM integrated robotics curriculum on elementary school students' attitudes toward STEM and perceived learning in an afterschool setting. Three elementary school teachers and 18 fourth to sixth graders participated in an eight-week-long program. Quantitative and qualitative data were collected and analyzed, and showed students' attitudes toward math improved significantly at the end of the robotics curriculum. Three specific areas of perceived learning were identified, including STEM content learning and connection, engagement and perseverance, and development and challenge in teamwork. The findings also identified the opportunities and challenges in designing a STEM integrated robotics afterschool curriculum for upper elementary school students. Implications for future research studies and curriculum design are discussed.

Keywords Educational robotics · STEM · STEM attitudes · Integrated STEM · Elementary school students

Introduction

Robotics has been lauded as an emerging approach to engaging K-12 students in learning science, technology, engineering, and mathematics (STEM). Recent research has suggested that the value of robotics in education lies in the hands-on opportunities that engage students in applying the knowledge and skills they have learned from various disciplines (Eguchi 2014; Nugent et al. 2010; Scaradozzi et al. 2015). Robotics activities can situate learning of abstract concepts and problem-solving skills through experiential learning wherein students can create, observe, and interact with physical objects (Petre and Price 2004). Robotics activities can also provide a meaningful context for integrated STEM education where students apply concepts and practices from relevant STEM subjects to solve real-life problems. Integrated STEM education is "an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems" (Moore et al. 2014, p. 38). Incorporating robotics into school curricula has been found to benefit students in a myriad of ways, including the development and application of STEM knowledge, computational thinking, problem solving skills, creativity, persistence, social interactions, and teamwork skills (Altin and Pedaste 2013; Bers et al. 2014; Kandlhofer and Steinbauer 2015; Taylor 2016).

Despite the potential multidisciplinary benefits as a result of robotics education, several challenges prevent a more extensive adaptation of educational robotics in K-12 schools. A

✉ Yu-Hui Ching
yu-huiching@boisestate.edu

Dazhi Yang
dazhiyang@boisestate.edu

Sasha Wang
SashaWang@boisestate.edu

Youngkyun Baek
youngkyunbaek@boisestate.edu

Steve Swanson
STEVESWANSON@boisestate.edu

Bhaskar Chittoori
bhaskarchittoori@boisestate.edu

1 Department of Educational Technology, Boise State University, 1910 University Dr., Boise, ID 83725-1747, USA

2 Department of Mathematics, Boise State University, Boise, ID, USA

3 Division of Research and Economic Development, Boise State University, Boise, ID, USA

4 Department of Civil Engineering, Boise State University, Boise, ID, USA

Published online: 02 April 2019

systematic literature review (Benitti 2012) found that robotics has mostly been taught in schools as a subject of its own without being integrated with other school subjects. Most of the existing robotics curricula focus on learning robotics and programming rather than integrating and applying subject-specific knowledge to solve problems using the principles of robotics (Kopcha et al. 2017). As a stand-alone subject, robotics is less likely to appeal to teachers who find it challenging to add an additional subject into the existing packed curriculum which is often driven by standardized-testing. Furthermore, such robotics curricula often only attract students who already have an interest in robotics and programming. When a robotics curriculum is designed so that it emphasizes the application of STEM -based problem solving, teachers are able to integrate it into, or use it as supplement for, their existing STEM related subjects. And there is an increased potentiality to engage students with a broader range of interests (Benitti 2012).

The lack of age-appropriate robotics curricula also presents another barrier (Barr et al. 2011; Khanlari 2016; Kopcha et al. 2017). Existing educational robotics activities and engineering curricula are designed for middle and high school learners (Benitti 2012; Elkin et al. 2014). Only recently has there been a push to introduce robotics to younger learners in kindergartens and elementary schools as several age-appropriate robotics kits have been developed (Ching et al. 2018a). In order to encourage the adoption of robotics education in elementary schools, STEM integrated and age-appropriate robotics curricula will need to be developed. In this study, a STEM integrated robotics curriculum, designed and developed for upper elementary school students, was examined for its impact on students' STEM attitudes and perceived learning.

Literature Review

Robotics in Education

Robotics activities in education offer opportunities for students to explore, create, and apply knowledge to solve real-world problems. Constructionism underpins learning with robotics. Building on constructivism's connotation to learning, Papert (1991) defined constructionism as learning that involves conscious engagement in constructing public entities that can be shared with others. With robotics activities, learners construct their knowledge structures through robot building and programming, representing their understanding through constructed artifacts in the physical world. Learning through the creation of these artifacts can be particularly effective because it fosters the processes of construction, testing, and the revision of knowledge (Papert 1991). Additionally, personal knowledge is demonstrated in the artifacts that can be shared with others for feedback (Kafai and Burke 2015).

Robotics has long been leveraged as a more concrete approach to teach computer programing. Through programming a tangible robot, learners receive additional sensory feedback from the robot's enactment of the digital codes, transforming the learning from an abstract concept into reality (Ching et al. 2018a). This approach supports young learners by providing more concrete learning experiences when learning abstract programming concepts (Petre and Price 2004). Research suggests that tangible learning experiences improve motivation, self-ownership over learning among students, and overall interest in STEM-related subject matter (Bers et al. 2014; Nugent et al. 2010; Ucgul and Cagiltay 2014).

Robotics and Integrated STEM Education

Robotics activities provide hands-on opportunities that engage students through the application of the knowledge and skills they have learned across disciplines (Nugent et al. 2010; Scaradozzi et al. 2015). Traditionally, STEM subjects are taught separately and have predominately been focused on mathematics and science in primary schools (NRC 2014). Learners rarely apply the concepts learned in the math and science classes to solve real-world problems and thus have trouble understanding the purposes and real-world applications of the concepts. For example, fourth graders learn the concepts of angles and measuring angles in math classes as specified in the Common Core State Standards (National Governors Association Center for Best Practices, and Council of Chief State School Officers 2010), but they rarely have opportunities to measure angles in the context of real-world problems (e.g., program a robot to turn a specific angle to avoid obstacles). The committee on Integrated STEM education (NRC 2014) noted that:

> Connecting ideas across disciplines is challenging when students have little or no understanding of the relevant ideas in the individual disciplines. Also, students do not always or naturally use their disciplinary knowledge in integrated contexts. Students will thus need support to elicit the relevant scientific or mathematical ideas in an engineering or technological design context, to connect those ideas productively, and to reorganize their own ideas in ways that come to reflect normative, scientific ideas and practices. (p. 5)

Robotic activities have the potential to serve as meaningful contexts for an integrated STEM education experience that facilitates knowledge and skill application, as well as one that fosters students' understanding of the connection between multiple STEM disciplines. In his review of robotics literature, Benitti (2012) urged the development of cross-disciplinary curricula and activities that integrate robotics with other subjects (e.g., science, and engineering). Robotics activities that aim to develop STEM knowledge through skills application and connection will help draw students with an interest in STEM, as well as those interested in robotics. Arguably, STEM integrated robotics curricula are more likely to gain buy-in and implementation from teachers as robotics is not the end-goal of the learning, but rather a means to apply STEM concepts and processes for problem-solving (Kopcha et al. 2017).

Instructional Approaches for STEM Integrated Robotics Activities

Two common pedagogical approaches can be used to guide the design of a STEM integrated robotic curriculum. First, a project-based learning (PBL) approach can be used to structure the overall curriculum (Ching et al. 2018b). A PBL approach enables the design of inquiry activities where students have the opportunity to investigate authentic topics or problems, and can engage in learning through the active creation of artifacts (BIE 2017). In PBL, teachers act as facilitators to guide students during the hands-on activities, such as researching science topics, building robots, and practicing programming. This empowers students to self-direct their learning and take ownership of their experience, thus leading to a more engaging learning process.

Second, the design of a STEM integrated robotics curriculum can incorporate a functional environment to anchor the application of STEM knowledge, thus providing a meaningful context for robotics activities. A functional environment often involves an authentic, complex, and open-ended problem in which learners contextualize learning (Kopcha et al. 2017), and one that can help motivate students as they see how knowledge becomes functional during problem-solving (Pea 1987). A functional learning environment in the context of educational robotics requires the application of multiple STEM principles through building and programming a robot to solve an authentic problem (Kopcha et al. 2017). These experiences lead to deeper knowledge construction and context-specific understandings of how various STEM concepts and processes are interconnected, and could support students in developing more positive attitudes toward STEM subjects (Stohlmann et al. 2012).

Student STEM Attitudes

Previous research on STEM education found that students' attitudes toward STEM are critically associated with their later engagement in STEM fields. In a STEM attitudes instrument, Unfried et al. (2015) defined STEM attitudes as a composite of both self-efficacy and expectancy-value beliefs (Eccles and Wigfield 2002) in STEM:

> Self-efficacy is the belief in one's ability to complete tasks or influence events that have an impact on one's life (Bandura 1986) …Expectancy-value theories posit that individuals regularly assess the likelihood of attaining specific goals and appraise the value gained or lost from such attainment (Eccles and Wigfield 2002; Wigfield and Eccles 2000). (p. 623)

Studies found that students' interests in science and math in elementary school were correlated to their future degree selections in STEM areas (Maltese and Tai 2011), and accurately predicted their course selection in high school (Simpkins et al. 2006). With the increasing demands of and interests in a STEM proficient workforce, more interventions aiming to develop positive attitudes in elementary school students towards STEM have been developed and tested. Research also suggests that informal STEM learning experiences, such as camps and after-school programs, have increased students' attitudes towards STEM, and have positively impacted their performance on assessments on STEM concepts for middle and high school learners (e.g., Binns et al. 2016; Sha et al. 2015; Williams et al. 2007). However, research examining how informal STEM learning experiences affect elementary school students is less prevalent.

Research Purpose and Questions

This paper reports a case study that examined the impact of a STEM integrated robotics curriculum on upper elementary students' STEM attitudes and perceived learning. A case study uses a real-life situation or context as its research setting and addresses both descriptive and exploratory questions, and/or those questions that typically begin with 'what' or 'how' (Yin 2012). The curriculum was tested in an after-school setting so that students and teachers experienced the curriculum without academic pressures. Two research questions guided this study:

1. How does the STEM integrated robotics curriculum impact students' attitudes toward STEM?
2. What are perceived student learning in the STEM integrated robotics curriculum?

Research Method

The Context and Participants

This study took place after-school, in a community center serving a Title I elementary school (at least 45% of its students receive free or reduced lunches) in a northwestern state in the United States. Recruitment information about the no-cost after-school program was sent out to students going to the community center after-school. Eighteen fourth to sixth-grade students (12 boys and six girls) voluntarily participated with consent from their parents/guardians. Among the 18 students, nine students were in fourth grade, three in fifth grade, and six in sixth grade. Three elementary school teachers (from the specific school that the community center served) were recruited by the school district STEM coordinator. Each teacher led two small teams of three students, for a total of six students per teacher. Teams were formed by the teachers with the consideration of having a balanced gender and grade level distribution among the groups. Each teacher was familiar with some of the students either because they had the students in their classes or on athletic teams before. Only one student had previous experience with robotics and programming, and about two-thirds of the students had experience with Lego building.

The STEM Integrated Robotics Curriculum

The STEM integrated robotics curriculum, *Life on Mars*, aims to engage students in learning and connecting science, engineering, and technology. The curriculum was designed by an interdisciplinary team including faculty members in educational technology, math education, and engineering, as well as a former NASA astronaut, along with input from a local school district STEM coordinator. This robotics curriculum allows students to explore and experiment with STEM and robotics concepts over a comparatively longer period (e.g., 16 sessions over 8 weeks). Exposing learners to a particular topic over an extended period of time leads to prolonged engagement in the topic and ample opportunities for knowledge and practice application. Table 1 shows the STEM concepts and practices which this STEM integrated robotics curriculum intended to develop. The design of the curriculum explicitly addressed science, technology, and engineering concepts and practices. Math-related concepts and practices were assumed to already exist in students' prior knowledge, and therefore were not explicitly taught within this curriculum. The italicized items in Table 1 present the concepts and practices learners used during the hands-on problem-solving experiences or artifact creation processes, but were not part of the specific learning goals taught in this curriculum.

The curriculum design follows a project-based learning framework that uses driving questions and sub-questions to guide inquiry activities. Table 2 presents the enacted *Life on Mars* robotics curriculum. By leveraging inquiry activities, scientific concepts, robotics, and programming concepts were introduced during the first 4 weeks of the curriculum. Students researched and discussed the science of life and topics related to Mars in small teams guided by the teachers. Students also collaboratively assembled a basic robot with various sensors attached using manufacturer-provided instructions (online instruction here: https://bit.ly/2Se1dHU). Students then learned to program the robots with Lego EV3 software, which features a drag-and-drop programming interface. Students watched programming tutorials followed by practicing programming the robots. Starting from the 5th week of the curriculum, students designed, assembled, and programmed a robot with useful features for search life on Mars. Most of the teams had some ambitious plans (e.g., a dragon like robot with wings and a tail, a robot with a claw to collect samples) but ended up just modifying the basic robots due to the technical challenges. Figure 1 presents student-designed robots for the final competition.

A functional environment was created to anchor learning and a robotics competition at the end of the *Life on Mars* curriculum. Previous research suggests that robotics competition is an effective way to situate learning and application of STEM concepts and skills (Altin and Pedaste 2013). In the first session of Week 7, the simulated Mars environment was presented to the students and the goals and rules of the final competition were explained. The final competition challenged the students to use their robots in a race to detect water (a piece of green paper, as an indication of life) on a simulated Mars environment built by the researchers (see Fig. 2). Students were only allowed to write a program which allowed the robots to navigate the simulated Mars environment and search for water from three different starting points. Students spent a session planning for their programming solutions and the following two sessions programming their robots and testing their solutions in the simulated Mars environment. The team robots competed to race to the water in the last session.

Table 1 Concepts and practices involved in the STEM integrated robotics curriculum

	Science	Technology	Engineering	Mathematics
Concepts	Forms of life; Mars (location, environments, landscapes, weather); Indications of Life on Mars	Robots (purposes; components; functions); Programming concepts (sequence; sensors; conditional statements; loops)	Engineering design process	*Angles; Distances; Multiplications*
Practices	*Making hypotheses; Data gathering through reading and discussio*n	Using computers to program robot movements with sensor inputs	Beginning with a problem; Designing and sketching robots; Building robots; Testing programs	*Measuring distances; Estimating angles (for robot turning)*

The italicized items in Table 1 present the concepts and practices that learners used during the hands-on problem-solving experiences or artifact creation processes, but were not taught specificaly in this curriculum

Table 2 Enacted "Life on Mars" robotic curriculum

Week	Session topics/activities
1	Session 1: Research Forms of Life and What is a robot? Explore Lego Mindstorms components Session 2: Assemble a basic robot
2	Session 3: Assemble robots; Program robots to move and turn Session 4: Research the environment of Mars; Program robots with sensor functions
3	Session 5: Program and explore sensors more; Program with Wait Block Session 6: Sketch a simulation of Mars; Program with Switch Block
4	Session 7: Program a simple robot for advanced movement (moving till input from (color/ultrasonic/touch) sensors) Session 8: Discuss engineering design process; Design/Sketch a robot to explore Mars
5	Session 9: Disassemble previously built robots and build new robots Session 10: Assemble robots
6	Session 11: Assemble robots Session 12: Assemble robots; Program with Gyro sensor
7	Session 13: Planning for the final competition Session 14: Program and test for the final competition
8	Session 15: Program and test for the final competition Session 16: Final tune-up; Final competition

Curriculum Implementation

The teachers received a three-hour professional development one week before the implementation to help prepare them to facilitate the PBL robotics curriculum. The professional development entailed the following topics: 1) introduction of the Project-based Learning with the emphasis on teachers' roles as facilitators; 2) an overview of the *Life on Mars* robotics curriculum; and 3) a hands-on session that involved each teacher building a basic robot by following the provided instruction (this was the same basic robot students built in the curriculum).

The implementation of the curriculum occurred during the regular semester after school for eight weeks, with teachers leading two 90-min sessions per week. All three teachers and 18 students shared a single classroom, which supported a co-teaching model wherein one teacher led a session while the others facilitated their teamwork. Teachers took turns leading and facilitating throughout the duration of the program. Three students per team shared a LEGO MINDSTORMS Education EV3 robotics kit as well as a laptop used for programming their robot. For each session, at least one educational researcher and one robotics content expert attended to assist teachers and students. In addition, the former NASA astronaut also facilitated several sessions where students designed/sketched their own robots for Mars exploration, and programed their robots for the final competition.

Data Sources

Multiple data sources were used to understand the subject of interest and triangulate the data. Pre- and post-surveys were conducted to examine whether the learning experience impacted students' attitudes toward STEM by using the first three sub-scales of the Upper Elementary S-STEM Survey (Friday Institute for Educational Innovation 2012; Unfried et al. 2015). The first three subscales included 26 statements that measured student attitudes toward math (8 statements), science (9 statements), and engineering and technology (9 statements). Students rated each statement on a five-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neither disagree or agree, 4 = agree, 5 = strongly agree). Sample questions read "I am good at math" (math attitudes), "I might choose a career in science" (science attitudes), and "I believe I can be successful in engineering" (engineering and technology attitudes). Unfried et al. (2015) consulted subject matter experts to establish content validity of the S-STEM survey and used Cronbach's alpha to measure internal-consistency

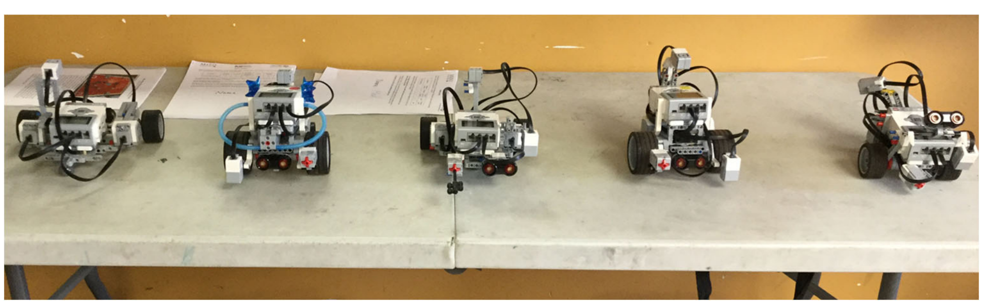

Fig. 1 Students designed robots for final competition

Fig. 2 A simulated Mars environment for final competition

reliability for the three scales: math (.85), science (.83) and engineering and technology (.84).

Qualitative data were collected to understand students and teachers' perceptions of student learning in this STEM integrated robotics curriculum. Three students from different teams, two boys and one girl who were available at the time of the focus group, participated in a focus group interview conducted to understand students' learning experiences and their perceived learning. Students at this age may not be open to express their ideas to unfamiliar researchers or provide rich information due to shyness. As such, additional data on perceived student learning were collected from interviews with the three teachers using semi-structured questions and weekly teacher reflections. Teachers directly work with their teams and they observed how well students grasped the learning materials and applied the learning to solve problems. Researchers also conducted passive observations that focused on the enacted curriculum, students and teachers' reaction to the designed materials and activities, and the challenges encountered. The observations aimed to provide insights for curriculum revisions while the observation notes were mainly used to support and triangulate findings from the student focus group and teacher interviews reflections.

Data Analysis

A paired t-test using pre- and post-survey data was used to examine the impact of the curriculum on students' STEM attitudes. The student focus group and teacher interviews were transcribed for analysis. A thematic analysis was employed to examine the qualitative data for themes by "identifying, analyzing and reporting patterns (themes) within data" (Braun and Clarke 2006, p. 79). Braun and Clarke (2006) further defined a theme as a unit of analysis that "captures something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set" (p. 82). Three major themes of perceived student learning emerged from the analysis, and will be discussed in the Results section: STEM content learning and connection, engagement and perseverance, and development and challenge in teamwork.

Results

Student Attitudes toward STEM

Table 3 summarizes the descriptive data (means and standard deviations) of the pre- and post-survey data on student attitudes toward STEM. Paired sample t-tests were performed to see if students' attitudes toward STEM had changed. The analysis showed that students' attitudes toward Math increased significantly ($p = .035$, $N = 14$) from the pre- to post-survey. The paired sampled t-tests did not show any differences between the pre- and post-survey on science attitudes or engineering and technology attitudes.

Perceived Student Learning from the Curriculum

While student learning was not measured directly in this afterschool robotics program, we reported perceived student learning based on qualitative data from the student focus group, teacher interviews, and teacher reflections. Overall, these data sources indicated that students perceived their learning

Table 3 Descriptive data of the subscales of student attitudes toward STEM surveys

	Pre survey Mean (SD)	Post survey Mean (SD)	t (p -value)
Math attitudes (5-point scale)	3.82 (.68)	4.18 (.72)	2.356 (.035)
Science attitudes (5-point scale)	3.46 (.68)	3.44 (.53)	−.200 (.845)
Engineering and technology attitudes (5-point scale)	4.23 (.46)	3.92 (.74)	−1.579 (.138)

experiences positively, despite challenges encountered along the way. Three major themes regarding perceived student learning emerged from the data: STEM content learning and connection, engagement and perseverance, and development and challenge in teamwork.

STEM Content Learning and Connection

During the interview, students were probed on their learning experiences in the program, and it was evident that building and programming robots were the most prominent aspects of their learning. All three students who participated in the focus group believed that their learning about programming would be the useful in their future; one student specifically noted that she liked the progression of learning the foundational programming skills to more complex programming skills. Another student indicated that "When we were also doing the *coding* it involved *technology*, and so I can see how technology comes into it."

All three teachers worked closely with their assigned student teams during the process to guide and facilitate student learning. Two teachers commented on students' learning in technology in their reflections:

> During coding, students constantly are discussing the program and are starting to use language like "block", "loop", and naming the sensors. Their knowledge of the program and coding is definitely growing. [Teacher A, Technology]
> When figuring out how to program our robots this past week, I watched my students really struggle for the first time. I was really impressed on how well they applied what they had already learned with coding in the weeks prior to try and apply it to what they were learning. [Teacher B, Technology]

At the beginning of the curriculum, students learned science by researching about the planet Mars, as well as forms of life. One student commented on the science learning and stated that:

> There's a bit of *science* because in the beginning we were talking about life on Mars and we had to read articles about scientists.

Teacher A also wrote in her reflection about students' learning of science:

> In the whole group setting, students were discussing the environment of Mars by making connections to the research they read or saw. Also, when students were presenting their simulations, they used a lot of scientific research to support their sketches.

A student reflected on the connections between engineering and math in this experience by explaining how he calculated the number of bricks needed for building robots. Another student commented on how much math he used during the process in order to program the robot's movements. He said:

> I had to measure something out, then I had to figure out how many *rotations i*t would be, then I had to multiply and subtract, then *add* and *subtract,* and then *multiply* and *divide a*gain, all just to figure out one simple thing.

In the teacher interview, Teacher A also commented on how students used math to help prepare for programming. She said:

> As we got more into the program I saw like the mathematics kinda within it. Like they had to measure how far they were going to …sense the rock. Like that was really cool that they were able to use those types of measuring tools and bring in that math.

Among the various STEM content learning experiences, building original robots from scratch presented the lion's share of challenges for students. Due to lack of prior experience, ambitious designs, and the lack of appropriate Lego bricks, some student teams spent up to four sessions building a functional robot. One student commented that "I learned that building robots is not easy." Teachers reflected this challenge in their weekly reflections which reported that:

> It was really hard for the students to build the robots because they didn't have all of the pieces. Some groups were more successful when it came to designing a robot without instructions. This is because they had background knowledge and experience. Other groups really struggled without the instructions. Once we got some of the pieces, it became a little easier. (Teacher A)
> This week I think myself and the students were both a little frustrated with the pieces that we didn't have. I think everyone did a nice job of finding solutions to that problem. (Teacher B)

Engagement and Perseverance

Most of the students were motivated to participate in the program and engage in hands-on robotics activities. One girl commented that:

> My favorite part of the program was the robots and the coding because I never had ever coded and when I tried it out it was actually fun.

Another boy also concurred that:

> The part of the project that I liked the best was probably making the robot and programming it.

Teacher A, in her reflection, wrote that her students asked if they could stay longer to work on the project and they also said they could not wait for the next section, an indication of high engagement in the program.

To increase students' motivation and engagement, the curriculum also included a Question and Answer section where students could interact with the former NASA astronaut on the research team. The astronaut guided and supported students' thinking about how to code for the final robotics competition, served as a role model for students, and encouraged their participation in STEM activities. One student stated that he liked the fact that an astronaut came in to work with them and helped them think about the problem-solving strategies. Another student was so moved by the experience that they expressed interest in becoming an astronaut.

As mentioned earlier, students encountered significant challenges in building original robots from scratch. Nevertheless, the teachers observed that students persevered through these difficult learning situations, another indication of students' motivation in the subject. Teacher C said:

> I was so amazed with, and this was with every group, their ability to persevere through this [afterschool program]. ...some days they were frustrated but they would always come in with a smile on their face, ready to go, like ready to try something new.

The three students who participated in the focus group unanimously indicated that they would recommend this program to their friends and they hoped to see additional programs like this in the community center and their classrooms. The female focus group participant said she wanted to introduce this experience to all her female friends so that they, too, could have the experience of building and programming robots, activities that her friends thought only boys would do.

Development and Challenges in Teamwork

Students worked in small teams of three or a large team of six (a combination of the two small teams) throughout the program. Teamwork was designed to foster collaborative knowledge construction, but was also necessary due to the limited sets of robotics kits available. Throughout the program, both the development of and challenges in teamwork were observed and reported. Student interviews corroborated these observations, indicating that teamwork was not easy. A student commented on his teammate's lack of interest in coding, and as a result, he had to work alone writing code. Another student said:

> I would say teamwork is not always easy, sometimes me and my partner would get into a disagreement about how the way our robot would look. …We got in an argument about how many sensors we were going to use in the competition.

However, most teams negotiated and agreed on solutions as their working relationships developed over time. For example, the student whose teammate was disinterested in coding found himself in charge of the coding for the robot, which allowed his teammate to work on building and modifying the robot using Lego bricks. Additionally, the student who expressed that teamwork was not always easy reported that she and her teammate slowly started to agree with each other and finally worked out a plan. While not all teamwork conflicts resolved themselves organically, the prevalence was not notable enough to report further.

While most of the students were motivated and engaged, the researchers' field notes indicated that some students showed signs of boredom from time to time. This mostly occurred while students waited for their turn to assemble the robot with the robotics kit or program on the laptop since they needed to be shared among the three students. Finally, it was also noted that not every student took advantage of opportunities to practice programming or to build robots as a personal choice, or due to more dominant teammates.

Discussion

Student Attitudes toward STEM

The *Life on Mars* curriculum was designed to synthesize science, engineering, and technology as a means of providing an integrated STEM learning opportunity. After participating in the program, student attitudes toward these subjects, excluding math, did not improve significantly as measured by the survey instrument. This result aligns with some robotics studies in informal settings. Conrad et al. (2018) found that elementary, middle, and secondary students' attitudes toward STEM did not change significantly after a week-long day camp, which may be due to the short length of the intervention. Leonard et al. (2016) found that a pilot study of an intervention consisting robotics and game design did not result in changes in attitudes toward STEM for the participating rural and indigenous middle school students. In the current study, the timing and difficulty levels of the activities may explain the lack of improvement in students' attitudes toward science, engineering, and technology. The science-relevant activities were introduced early on in the curriculum and therefore students might have forgotten these topics. Alternatively, it is also possible that the designed curriculum did not allocate sufficient amount of time to science-related hands-on activities which would lead to changes in science attitudes in learners. Descriptive data showed that engineering and technology attitudes decreased slightly but insignificantly. Two possible reasons to explain these results, based on the observation data, suggest: 1) building the robot from scratch presented significant challenges for students, and 2) the lack of sufficient time to work on the coding elements of their project in preparation for the final competition frustrated many students. Leonard et al.'s (2016) findings suggested that students needed to overcome the learning curve associated with the MINDSTORMS programming. Despite these possible explanations, additional interventions (e.g., teachers' use of relevance statement (Schmidt et al. 2018)) may help students' development of a more positive attitudes or interests in STEM.

In this study, student math attitudes increased statistically from the pre-intervention to the post-intervention. Although math was not intended as the primary learning focus in the curriculum, it turned out to be salient to students when they applied math during the problem-solving process. For example, students used a yardstick to measure the distance between objects (e.g., from the starting line to the rocks) in a simulated Mars environment in order to program precise and accurate robot movement (e.g., moving forward, making turns, and avoiding rocks) in preparation for the final competition. Field observation notes and student focus group data also revealed that students used math when they built the robots (e.g., calculating how many bricks to use) and programmed robots for movement (e.g., calculating how many rotations the motors needed to turn). Together, these data suggest that the robotics activities provided students the opportunities to see how math could be used in an authentic setting, which in itself is a compelling reason to explain students' positive attitudes at the end of the program. Despite the statistical difference in student pre- and post-math attitudes, the limited differences reflected in the mean scores call for caution in the interpretation of the results. Future studies with deliberate design aiming to develop positive attitudes in math through educational robotics are needed.

Student Learning Successes and Challenges

The findings revealed that students positively perceived STEM content learning and connection after participation in the afterschool robotics curriculum. In addition, most of the students were motivated and engaged in the curriculum. The integrated STEM robotics curriculum provided opportunities for the development and application of various STEM concepts and processes. Based on the student focus group and teacher interviews, perceived student STEM content learning was observed in science (knowledge about Mars and various life forms), technology (robot programming), and engineering (robot building). Teachers also observed that students developed perseverance as they faced challenges during the learning process. This finding supports previous research that robotics activities helped develop persistence when students encountered challenging and complex learning scenarios (Kopcha et al. 2017).

Among all the components in the curriculum, building robots was found to be challenging for the fourth to sixth grade students. Kopcha et al. (2017) observed that fifth graders struggled while building their robots, and some students were reported having difficulty following the provided directions guiding them through the necessary steps to assemble their robot. In this study, building robots by following instructions did not emerge as an issue. However, students did encounter significant challenges building and assembling original and functional robots from scratch, which took as many as four 90 min sessions to complete. While LEGO MINDSTORMS robotics kits are designed for learners age 10 and up, the learning curve for building a novel robot is steep for fourth to sixth graders who have no prior experience in robotics. Prior robotics research revealed that robot construction relies on a strong understanding of the different components of a robot (Slangen et al. 2011). These different components of the robots include a frame with static components (e.g., bricks), dynamic mechanical components (e.g., gears, axles), electronic components (e.g., sensors), and electro-mechanical components (motors). The understanding of the relationships among these components is considered a necessary foundation for students to design and build robots that are "stable and strong enough to enable the execution of the function(s)" (Slangen et al. 2011, p. 452). In the future, when a learning goal involves the construction of an original and functional robot, it is highly recommended that students develop a deep understanding of the various components of robots prior to embarking on the design and construction phases.

Using robotics to solve authentic problems presents excellent opportunities for meaningful collaboration among students (Kopcha et al. 2017). Research has found that student collaboration significantly impacts student motivation, student confidence, and knowledge construction through robotics (Leonard et al. 2016). In this study, most of the teams gradually developed teamwork skills. However, it was observed that teamwork was more successful in some teams than in others. Teamwork proved to be challenging for those teams where 1) teammates did not commit to the program by showing up regularly, and when 2) a teammate dominated the programming tasks, isolating their peer(s). The need to share technology (laptops in particular) exacerbated the lack of equal learning opportunities for all participating team members. Especially on a tight deadline, students who showed proficiency at programming were more likely to take the lead due to efficiency concerns, leaving others in the team with fewer opportunities for practice. A way to mitigate this issue would be to provide every student a laptop, which will allow all students to practice their programming skills. A team can still share a robotics kit, as teamwork has been shown to foster the robot building activity. To further develop students' collaboration skills, future studies may also consider assigning student roles to foster the collaborative problem-solving process and maintain student engagement (Taylor 2016).

Lesson Learned in Designing a STEM Integrated Robotics Curriculum

The goals behind the designing and implementing a STEM integrated robotics curriculum included a desire to connect robotics with other disciplines as a means of fostering STEM attitudes in upper elementary school students, as well as to create a context wherein students could solve problems using robots by applying their existing knowledge of various STEM disciplines. A unique challenge surfaced however, and that was the limitation of learning time. As the *Life on Mars* curriculum relied on weaving together multiple disciplines, including science, engineering, and technology, it was challenging to find solutions that would afford sufficient time for each discipline. The research showed that successful and meaningful learning experiences were highly dependent on learners' prior knowledge and experiences in the various disciplines due to the time constraints. Building an original and functional robot was found to be extremely difficult for upper elementary school students with limited experience in robot design and building. They had ambitious ideas compared to the limited resources (insufficient Lego bricks), and lacked fluency in the principles of robotics, such as understanding how robot parts function together as a system. It was also noted that upper elementary school students chose to spend more time on the appearance of their robots than the functionality. Students who had prior experience with constructing robots with Lego bricks completed the activities more effectively and efficiently.

As multiple learning goals compete for limited learning time in a STEM integrated robotics curriculum, prioritizing learning goals is highly recommended. For example, for upper elementary school students, the inclusion of designing and building original robots may be optional if the learning goal is to have a functional robot to solve a problem, regardless whether students design the robots or not. As students and teachers in this study suggested, students could follow the instructions to assemble a robot and then choose to modify the robot design as they see fit based on the problem to be solved, further supporting development of students' critical thinking skills. This alternative may help reduce the challenge and frustration of building an original robot and would thus allow for more time to practice their programming skills, an area both students and teachers expressed a desire to spend more time on in this study.

Conclusion

This case study explores how a STEM integrated robotics curriculum impacts upper elementary student attitudes toward STEM and their perceived learning of it in an informal learning setting. With the small sample size and the unique learning context, the results need to be interpreted with caution. In addition, the results of student learning are based on self-reported and observational data, not from direct measures and therefore future studies are encouraged to measure student learning of the intended STEM outcomes. The impact of this STEM integrated robotics curriculum can be further examined and established by implementing it with a larger population in various informal learning contexts.

This study found that most students had positive learning experiences in this STEM integrated robotics curriculum. After participating, students reported having more positive attitudes toward math, perceived STEM content learning and connection, developed perseverance, and improved teamwork skills. Overall, the tested STEM integrated robotics curriculum successfully engaged students in solving problems by leveraging robotics and STEM knowledge. Recommendations for future studies include prioritizing learning goals and providing each student a laptop for programming practice, which can help improve the curriculum and ensure enhanced learning experiences for all students.

Funding This material is based upon work supported by the National Science Foundation under Grant Number 1640228. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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