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Increasing Stem Literacy Via an Informal Learning Environment

Christa D. Jackson
Iowa State University, jacksonc@iastate.edu

Margaret J. Mohr-Schroeder
University of Kentucky, mmohr2@g.uky.edu

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Iowa State University

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University of Kentucky

Abstract

STEM literacy is the ability to apply concepts from science, technology, engineering, and mathematics to solve problems that cannot be solved using a single discipline. In this qualitative study, we examined how a robotics course in an educator preparation program that integrates informal learning experiences increased teachers' exposure to a variety of STEM learning activities and impacted their STEM literacy. The results revealed the teachers developed a deeper understanding of STEM and broadened their STEM literacy through participating in the informal learning experiences.

Keywords: Field experience; Informal learning; STEM literacy

STEM literacy is not a conglomeration of the four silos that comprise STEM (science, technology, engineering, and mathematics). It does not simply take components of scientific literacy, technological literacy, engineering literacy, and mathematical or quantitative literacy from each of the STEM disciplines in order to generate STEM literacy. Instead, it involves the transdisciplinary integration of STEM disciplines and the tools and knowledge necessary to apply STEM concepts to solve complex problems (Balka, 2011). STEM literacy is the ability to apply concepts from STEM to solve problems that cannot be solved using a single discipline or would benefit from a creative solution involving multiple disciplines. An understanding of STEM literacy as a unique tool set to create and use knowledge of and across disciplines arises from applying the concept of literacy to disciplines individually and holistically (Mohr-Schroeder, Cavalcanti, & Blyman, 2015).

An integrated approach to STEM education is needed to prepare STEM teachers to teach students in the 21st century (Ostler, 2012). Prospective and in-service teachers who have opportunities to experience and apply an integrative pedagogy develop a broader understanding of STEM than those who have a degree in a single STEM discipline. Although research exists on how using an integrated approach to teach STEM subjects can increase student motivation and achievement,

limited research exists on ways to support teacher development that integrates STEM disciplines (Honey, Pearson, & Schweingruber, 2014). The purpose of this study was to examine how a teacher education program course in robotics that was situated in informal learning experiences impacted participants' STEM literacy.

STEM Literacy

Before many students enter eighth grade, they conclude that the STEM subjects are too challenging, boring, or uninteresting (President's Council of Advisors on Science and Technology, 2010). In fact, the National Governors Association Center for Best Practices (2005) reported that "only three out of 10 U.S. eighth-graders are proficient readers [(National Center for Educational Statistics, 2003)]" (p. 1), and students who are not proficient readers (70%) are less likely to take advanced classes in mathematics and science. Research has shown that more exposure to a variety of STEM opportunities has a long-term effect on individuals and on the overall STEM education community (Wai, Lubinski, Benbow, & Steiger, 2010). Consequently, the Kentucky Council on Postsecondary Education STEM Task Force (2008) posits a critical need for STEM literacy, suggesting that "teacher education must focus on enhanced STEM disciplines and embedded pedagogy" (p. 6). This focus will, in turn, begin to develop STEM literate educators.

Prospective and in-service STEM teachers need to have content-specific knowledge as well as the ability and confidence to teach across subjects to effectively integrate STEM learning experiences in their own classrooms (Honey et al., 2014). Not only must prospective and in-service STEM teachers have knowledge of ways to integrate STEM, but they also need to have positive dispositions toward STEM and be STEM literate. Bybee (2010) defined STEM literacy as "the conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues" (p. 31). Zollman (2012) extended this definition to include cognitive, affective, and psychomotor domains. Unfortunately, many people, including prospective and in-service teachers, have a negative disposition toward STEM. Therefore, it is important to include cognitive and affective change strategies such as problem-based learning; student-centered, hands-on STEM related activities and projects; and cooperative learning in order to promote more positive dispositions toward STEM (Lee & Nason, 2012).

Informal Learning Environments

Informal learning experiences provide opportunities for prospective and in-service teachers to apply what they learned in coursework in an authentic environment outside of the classroom (Jackson, Mohr-Schroeder, & Little, 2014). Furthermore, teachers have an opportunity to reflect on those experiences and, subsequently, apply what they have learned in ways that will transform education (Swick, 2001). Research suggests that pedagogy rooted in informal learning environments, such as experiential pedagogy, grounds the learning in experience (Dewey, 1938; Root, 1997) for prospective and in-service teachers. The See Blue STEM Camp is one such informal learning environment in which teachers can engage in authentic tasks that will increase their STEM literacy and help them become more effective STEM teachers.

The See Blue STEM Camp is a week-long (5-day) summer day camp for middle school students (students entering Grades 5–8). The camp focuses on authentic hands-on sessions in which students are given opportunities to engage in a variety of STEM fields. Additionally, during the camp, the students participate in a daily session of Lego Robotics and attend other sessions focused

on STEM content in authentic learning environments. For example, students go to the biology lab to learn about drosophila (fruit flies) from a biology professor and her graduate students. All the topics and content in the See Blue STEM Camp focus on the eight Standards for Mathematical Practice from the *Common Core State Standards for Mathematics* (National Governors Association Center for Best Practices & Council of Chief State School Officers [NGA & CCSSO], 2010) and the eight Scientific and Engineering Practices from *A Framework for K-12 Science Education* (National Research Council [NRC], 2012), which are used in the *Next Generation Science Standards* (NGSS Lead States, 2013). These practices are listed in Table 1.

The language of the Standards for Mathematical Practice (NGA & CCSSO, 2010) and the Scientific and Engineering Practices (NRC, 2012) reveal an extensive overlap in their attempts to support students in solving complex problems and participating in authentic learning experiences, thereby increasing their STEM literacy.

Table 1
Standards for Mathematical Practice and Scientific and Engineering Practices

Standards for Mathematical Practice	Scientific and Engineering Practices
1. Make sense of problems and persevere in solving them.	1. Asking questions (for science) and defining problems (for engineering)
2. Reason abstractly and quantitatively.	2. Developing and using models
3. Construct viable arguments and critique the reasoning of others.	3. Planning and carrying out investigations
4. Model with mathematics.	4. Analyzing and interpreting data
5. Use appropriate tools strategically.	5. Using mathematics and computational thinking
6. Attend to precision.	6. Constructing explanations (for science) and designing solutions (for engineering)
7. Look for and make use of structure.	7. Engaging in argument from evidence
8. Look for and express regularity and repeated reasoning. (NGA & CCSSO, 2010, p. 10)	8. Obtaining, evaluating, and communicating information. (NRC, 2012, p. 3)

Methods

This project utilized qualitative methods to answer the following research question: How does a teacher education program course that integrates informal learning experiences increase participants' exposure to STEM and impact their STEM literacy?

Population

The 32 participants in the study were graduate students in a STEM education doctoral program, undergraduate and graduate students seeking certification in mathematics or science education (Grades 8–12), and college-credit seeking high school students from a local STEAM (science, technology, engineering, arts, and mathematics) high school program. All participants were enrolled in an introduction to robotics course in the summer of 2014 or 2015. This course was a 4-week hybrid course (including face-to-face sessions in addition to asynchronous online modules) that was cotaught by an engineering professor and a STEM education professor at a large public

university in the southeastern region of the United States. Throughout the course, participants (a) gained familiarity with the interdisciplinary field of robotics and its growing impact on society; (b) developed the ability to direct robots using computer languages for communication; (c) gained familiarity with widely used computer programming constructs, including variables, assignment, looping, and conditional statements; (d) gained aptitude in understanding, designing, and evaluating patterns of logic and reasoning expressed as algorithms; (e) learned to practice argumentation and reflection on topics related to disciplinary content, including and especially ethics; and (f) became more comfortable and effective working in a team setting, particularly in analyzing and communicating logical and computational ideas with others.

Additionally, the robotics course gave participants opportunities to explore robots, engineering concepts, engineering design, and robotics curricular material for K–12 students. In the course, students learned about basic robotics communication and programming using the Lego Mindstorms EV3 robot. This robot was chosen because a majority of the participants in the course had ties to K–12 students and the state in which this course took place hosted and regularly supported First Lego League competitions in which a majority of school districts participate each year. After building the EV3 robots, students were required to program their robots to meet various challenges. The early challenges (such as drawing a square) required students to use "blocks" to program their robot to move forward, backward, and turn. "Loops" and "switches" were used for more challenging tasks that incorporated the use of sensors (e.g., program the robot to sense when it was 11 inches from the wall and then turn and return to the original position).

In order to apply what they learned in the first 3 weeks of the course, the participants were required to participate in a full week of the See Blue STEM Camp as group leaders for the 144 middle school students attending the camp.

Data Collection and Analysis

Data were collected for participants (who are, henceforth, referred to as teachers given their role in the camp) during the 2014 and 2015 See Blue STEM Camp. In their role as group leaders, the teachers participated in the camp's activities alongside the middle school students. The teachers were asked to complete daily reflections at the end of each day for the first 4 days of camp. The reflection prompts focused on what they learned, what they liked about what they learned in the content sessions, and what they did not like about what they learned in the content sessions. At the end of the camp, the teachers reflected on and synthesized their growth and learning in a two-page written final reflection. In addition, the teachers participated in a semistructured interview about their experiences working and participating in the See Blue STEM Camp.

The data (written daily reflections, final reflections, and interviews) were analyzed using a data reduction approach (Miles, Huberman, & Saldaña, 2014) along with the constant comparative method (Glaser, 1965; Glaser & Strauss, 1967). Using a constant comparative approach, we compared incident to incident, analyzing the data for similarities and differences (Charmaz, 2006) to discover patterns and themes that emerged from the data (Strauss & Corbin, 1998).

Results and Discussion

As the teachers participated in the informal learning environment of the See Blue STEM Camp via the robotics course, three prominent themes emerged from their reflections and interviews:

The teachers developed a better understanding of STEM, the teachers' instructional practices were enlightened, and the students exhibited excitement and interest, which all positively influenced the teachers' STEM literacy.

Understanding STEM

Prior to participating in the robotics course, a majority of the teachers did not have a clear understanding of STEM and what it looked like when students actively engaged in STEM activities. All of the teachers articulated that STEM was an acronym for science, technology, engineering, and mathematics; however, it was not until after they participated in the See Blue STEM Camp via the robotics course that they came to realize the true meaning of STEM. For example, one teacher stated, "They're really are all interconnected and kinda [*sic*] go together" (Teacher Interview, 2015). Another teacher further elaborated that STEM is "interdisciplinary education" (Teacher Interview, 2015) involving the four disciplines of science, technology, mathematics, and engineering, and you do not teach each discipline in isolation.

Although the teachers recognized STEM as interdisciplinary education, many of the teachers enrolled in the robotics course were current or future mathematics teachers who were extremely comfortable in their mathematical abilities but were not confident in their scientific and engineering abilities.

> All I am really good at (or really familiar with, I should say) is the mathematics part of STEM. The traditional mathematics classroom is what I was familiar with because that is all I had really ever seen. So needless to say I was a little nervous about stepping into a class and camp that dealt more with science and technology than mathematics. But now I've been through the class and camp, I see that they are all intertwined and I love it! (Teacher Final Reflection, 2014)

Another teacher also stated that he was confident in his mathematical skills as a future mathematics teacher, but he had not taken any science classes since high school and felt that he had limited abilities in engineering and technology (Teacher Final Reflection, 2015). After the camp, he felt "more connected to all of the disciplines" (Teacher Final Reflection, 2014).

Because a majority of the teachers were in-service or future mathematics teachers, they were primarily only confident in their mathematical abilities. As they participated in the See Blue STEM Camp, they deepened their content knowledge in various STEM disciplines. In one session that focused on energy, the teachers were surprised to discover that cement acts like a glue to hold concrete together. The teachers had the misconception that cement dries, and that is why it hardens. They were shocked to discover that this was not true. Instead, the cement undergoes a chemical reaction, hence why cement needs to sit untouched while it cures.

The teachers' understanding of STEM was broadened not only by the instructors' presentations but also by the middle school students participating in the camp, particularly during the robotics sessions. One teacher stated, "I didn't truly grasp the programming side until camp actually started. I would say the kids in the camp helped me more with understanding complex programming on the EV3s than anything else did" (Teacher Final Reflection, 2014). Another teacher stated, "It made me feel a little inept because of how long it took me to program the robots to do a square compared to how quickly the students could do it" (Teacher Daily Reflection, 2014). The majority of the teachers were impressed by the students' knowledge. In fact, one teacher selected a pair of students and followed them through the process of programming to modeling their robot's programming

functions. He learned that "each robot's programming was slightly different in the number of increments increasing and decreasing based on the programming function they were attempting for their robots" (Teacher Daily Reflection, 2014). Another teacher said she learned a lot helping students code their robots:

> I learned you can manually rotate a motor to see how many degrees it is turning. Also, the order in which the motor ports are selected in the code makes a difference. I'm not sure if this is also true for the EV3, but the NXT will not turn correctly if the ports are selected in the order opposite to the previous block in the code. (Teacher Daily Reflection, 2014)

The teachers were simply amazed at what the students could do and how quickly they picked up the programming language. The teachers recognized that not only were they teaching the students, but the students were also teaching them. "This is something that I think is very important for all future teachers to realize. Students will teach you just as much as you teach them" (Teacher Final Reflection, 2014).

Once teachers had a better understanding of STEM, they were excited about the different ways that they could take what they learned into their classrooms. The teachers were involved in a variety of activities, including extracting DNA, interacting with human organs, sending a magnetic ball through PVC and a copper pipe, and geocaching and mapping using Google Earth. They exclaimed how they would like to use all of the activities from camp in their classrooms. One teacher voiced some hesitation but realized the importance of such STEM activities:

> As a mathematician, we enjoy knowing a specific algorithm to solve a given problem. As a STEM educator and student, we must embrace several methods and different attempts to reach a certain result. I am nervous about working across disciplines because I am not an out of the box thinker. Recognizing this now is beneficial to my growth. (Teacher Final Reflection, 2014)

Many of the teachers realized that STEM was more about the integration of the four subjects, and the activities that they participated in via the robotics course and the See Blue STEM Camp broadened their view of STEM. One teacher stated, "I have learned some great ways to introduce integrated STEM activities to students for engineering, robotics and many other content shifts" (Teacher Daily Reflection, 2015). Another teacher summed it up by saying, "I love seeing STEM in action, not just theory" (Teacher Daily Reflection, 2015).

Instructional Practices

The majority of the teachers discussed the importance of including hands-on activities to keep students engaged in the lesson. From their experience with the camp, they recognized that students learned more through hands-on tasks. One teacher stated, "It seems like everyone had a lot of fun with the interactive stations. It is such a simple way to get students engaged, which is something I hope to bring to my classroom in the future" (Teacher Daily Reflection, 2014).

The teachers also gained first-hand experience in what it meant for a teacher to be flexible. They learned the importance of adapting their instruction in the moment. During camp, one of the robotics instructors had to adapt his instruction due to materials not being assembled. The teachers were glad they had the opportunity to see how to handle situations in which the lesson did not go as planned. "I gained insight in how to adapt to things not going right. [The instructor] was really good at adapting the plan and it is something that I would like to develop as a teacher" (Teacher Daily Reflection, 2014). One teacher realized that he has to be more flexible in how he

thinks about his own teaching. He remarked,

> I have had a very rigid view of mathematics and unfortunately that has influenced the way I teach. Math does not always have to be black and white, right or wrong, although there are occasions for that. I need to allow for flexibility. (Teacher Final Reflection, 2014)

The teachers also had to refrain from giving students the answers to STEM tasks. One teacher realized that he needed to work on his questioning strategies and let the students figure out the task for themselves so they could learn it.

> Sometimes it is best to have them walk you through the process and give some positive encouragement for what they did right. Usually having the students vocalize what they did gives them a way to hear when they actually missed a step. You can guide them with good questions if they still can't figure it out. There is a difference in giving the answer directly and asking probing questions to check for understanding. (Teacher Daily Reflection, 2014)

It is also necessary to provide students with multiple entry points to solve a task. A teacher commented, "There are multiple ways to learn a topic, and therefore as a future teacher, it shows me how important it is to explain something to my kids in different ways to best meet their learning [needs]" (Teacher Daily Reflection, 2014).

The teachers expressed that they were able to learn more about classroom management through this authentic experience. They realized the necessity of creating a positive classroom community. They expressed that the students worked well together, which was especially surprising to most of the teachers because the majority of the students did not previously know one another. One teacher commented, "Pretty much everyone was getting along with their partners . . . more people [were] becoming friends" (Teacher Daily Reflection, 2015).

Through this experience, the teachers recognized that not only were they teaching the students, but the students were also teaching them. One teacher remarked,

> While I was teaching, I was also learning, and while the kids were learning, they were also teaching me. This is something that I think is very important for all future teachers to realize. Students will teach you just as much as you teach them. (Teacher Final Reflection, 2014)

Another teacher further expressed,

> The amazing thing is I learned even more from the students during STEM camp. They were pointing things out to me that I didn't even know existed, so I feel confident in my knowledge both of the robots and the programming as well. (Teacher Final Reflection, 2014)

To sum it up, a teacher concluded, "The neat thing is that I have learned so much more about programming from watching, and talking to the kids; obuchenie (teacher and students learning from each other)" (Teacher Daily Reflection, 2015).

Students' Excitement

The teachers had an opportunity to witness students' excitement while learning mathematics and science. They expressed that seeing students' enthusiasm in these disciplines was rare. "I liked seeing students excited about learning! We do not see students interested in education and learning everyday, especially math" (Teacher Daily Reflection, 2014). Many of the teachers did not expect students to be so engaged in learning and enthusiastic about learning STEM concepts,

especially because many of the students were not enrolled in the camp because they enjoyed the STEM disciplines. One teacher commented, "I didn't expect them to be this excited, to be honest" (Teacher Interview, 2015).

Along with the enthusiasm of the students, the teachers also noticed that the students were very persistent and refused to give up, even when they were unsuccessful at completing various tasks. One teacher articulated, "I was impressed with the persistence of many of the groups. Even when some kids got frustrated, they refused to give up. It was awesome to see!" (Teacher Daily Reflection, 2014). Another teacher commented,

> My blue group started the Green City Challenge today and everyone (including myself) seemed overwhelmed with all of the different tasks they could try with their robot at first. But, after a while the students were getting the hang of it and learning to take the programming step by step. They were getting so into it and it was great to see them cheering when they accomplished something new. (Teacher Daily Reflection, 2015)

The teachers were amazed at how the students took ownership of their learning. They noticed that the students would ask for help but then would say, "Never mind, I've got it." The students realized that they did not need the assistance of the teachers to complete the task because they could figure it out on their own. After the students' successful completion of each task, the teachers noticed that they would jump up and down, smile, cheer, and take a "walk of victory."

Conclusions and Implications

The informal STEM learning experiences that the teachers engaged in were aimed at providing an embedded pedagogy to increase STEM literacy and learning in a context intended to influence the delivery of STEM learning in their classrooms. It is important that teacher education programs provide opportunities for teachers, both prospective and in-service, to develop and deepen their understanding of STEM literacy. As one teacher proclaimed, "I've had very limited experiences with STEM in general, so everything I've been learning has been new" (Teacher Interview, 2015). As educators, we need to engage teachers in experiences that foster their STEM literacy, which will ultimately support STEM teaching and learning.

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Authors

Christa Jackson
Associate Professor of Mathematics Education
Iowa State University
Email: jacksonc@iastate.edu

Margaret Mohr-Schroeder
Professor of STEM Education
University of Kentucky
Email: m.mohr@uky.edu