International Journal of Gender, Science and Technology
http://genderandset.open.ac.uk

Selected papers presented at the 5th Network Gender & STEM Conference, 29–30 July 2021, in Sydney, Australia

In association with

NETWORK GENDER & STEM educational and occupational pathways and participation

Increasing Middle School Girls' STEM Self-Efficacy with Soldering, Robots, and Mobius Strips

Anita Crowder & Kathleen Whittle

Virginia Commonwealth University

ABSTRACT

This case study explores the impact of an innovative four-day STEM camp for middle school girls from underserved communities in the United States on participants' STEM self-efficacy. STEM self-efficacy has been positively correlated to persistence and achievement in STEM subjects (Bandura & Locke, 2003), particularly for girls (Larose et al., 2006). Bandura (1977) wrote that the four sources of self-confidence are performance accomplishments, vicarious experience, verbal persuasion, and emotional arousal. The camp was designed to use a pedagogy of play and non-stereotypical activities to support youth agency and provide those four inputs to improve girls' attitudes toward STEM and STEM self-efficacy. The camp was facilitated by an all-female volunteer team of adults and secondary students to help enhance a sense of belonging. Each day focused on a different STEM field: science (Monday), technology (Tuesday), engineering (Wednesday), and mathematics (Thursday). Participants completed pre- and post-surveys on STEM attitudes and self-efficacy, created and shared reflective daily presentations (Coutinho, 2008), and took part in closing focus groups. Framework analysis of focus group transcripts and youth presentations identified four themes reflecting Bandura's supports for self-confidence (Srivastava & Thomson, 2009).

KEYWORDS

STEM, Self-efficacy, Identity

Increasing Middle School Girls' STEM Self-Efficacy with Soldering, Robots, and Mobius Strips

RELEVANCE
In the United States, people from minoritized communities, particularly women, are still underrepresented in STEM fields (Fry et al., 2021). This article describes a community-driven STEM camp for middle school girls that was designed to offer deep STEM experiences to increase participants' STEM self-efficacy and positive attitudes toward STEM careers as future goals. Pre- and post-survey results showed non-significant positive changes for participants, but qualitative analysis of artifacts and focus groups, as well as later interviews with former participants and volunteers, showed that engaging in these unique hands-on activities that challenged perceptions about STEM subjects and their own ability to learn them, had long term impacts on academic and career choices. Along with increasing interest and persistence in STEM for youth participants by leveraging non stereotypical STEM experiences, the camp created a culture of community outreach and volunteerism for the teen volunteers and, more widely, to other students at the high school where the camp was held.

Future scientists

The camp was designed by the authors, two female former engineers-turned-educators who worked at a public specialty high school focused on the arts and technology. The high school is located in a small urban city in the southern United States and draws its small student population from different school districts. The community surrounding the school has one of the lowest household incomes in the state with only one school in the district holding state accreditation. According to the US Census, the city, with a population of slightly over 31,000, is approximately 77% Black and 18% White, with the other 5% of the population consisting of other, or two or more, races. In 2021, the small city had one of the highest per capita murder rates in the country. This context is given to illustrate why the authors felt a sense of urgency to provide free, meaningful STEM programming to youth in this community that would be effective in supporting development of positive STEM attitudes and increased awareness of and self-efficacy for pursuing STEM careers.

It was an important mission of the authors to help strengthen the relationship between the specialty high school and the community where it is located. Both authors have personal ties to the small city outside of teaching at the high school and decided to develop free out-of-school STEM programming for middle school girls. After receiving permission from the high school's administration, the first camp took place in 2014 as a free one-day STEM experience for the participants. The camp later expanded to four days with a different focus each day. Because the camp was not created based on funding from a grant, the authors leveraged assets from the community, like local restaurants to supply food to participants, businesses for donations for purchasing supplies for the planned activities, and parents and families of students at the high school for the all-female volunteer staff. The camp was advertised publicly in local businesses and staff from the local school district assisted in recruitment of participants. By involving parents, it allowed the authors to discover and build relationships with female STEM professionals for future events and activities. Teen volunteers, including current students at the high school and recently graduated alumni who were attending college, were invited by the authors to assist and complete the staff. The camp's low implementation costs and reliance on volunteers and community stakeholders indicates that the camp may be replicated in other challenging contexts.

METHODOLOGY

Bandura's self-efficacy framework has been used in various contexts, including education, for decades. According to Bandura, the four factors contributing self-efficacy are performance accomplishments, vicarious experience, verbal persuasion, and emotional or physiological arousal (Bandura, 1977). When developing the STEM camp, the authors kept those factors at the forefront, as well as leveraging the indicators of the playful learning pedagogy: choice, wonder, and delight. Although most activities were first scaffolded with guided instruction and modeling, youth were able to explore freely within the set boundaries.

Over the past decade, the high school's Technology department has hosted STEM experiences for over 100 local elementary and middle school aged students. For the specific camp described in this case study, ten (10) participants between the ages of 9 and 11 years old, all of whom were from minoritized populations, responded to public advertising or were recruited by local school district personnel. To attend the camp, all youth were required to submit guardian consent, youth assent, and photo release forms.

This camp purposefully planned activities that built upon each other, offering increasing difficulty, challenge, and deeper cognition at each stage. Structuring the program this way offered youth a greater chance to succeed in tasks and build understanding around the engineering design process, in which failure is not the end of the process, but just another step in a continuous cycle. The use of an all-female staff made up of adults with experience in STEM and teen student volunteers with a foundational interest in STEM, the majority of whom were of color, provided role models for the youth participants to imagine a future self in STEM (Bettinger & Long, 2005). The daily agenda included time for collaboration and teamwork, where conversations and presentations exhibited aspects of verbal persuasion. Finally, the introduction to unusual STEM activities offered emotional arousal and curiosity and primed the participants for each day.

Participants were given a journal at the beginning of the camp in which to take notes on what they learned, and to use as a reference throughout the program. At the end of each day, teams of girls collaborated on presentations with prompts guiding them to reflect on the day, as well as project into the future. Every day, they answered the following questions: (1) What were your two favorite things you learned today? (2) What two things would you like to learn about [Science/Technology/Engineering/Math] in the future? (3) Did today's activities affect how you feel about [Science/Technology/Engineering/Math]? If they did, how? If they didn't, why not?

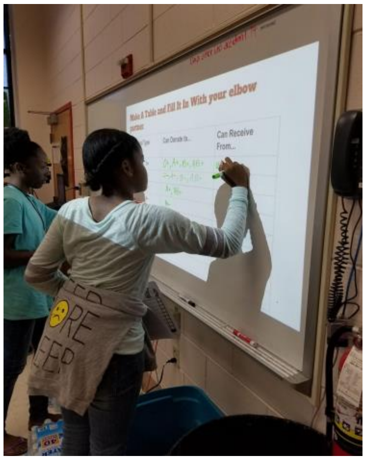
At the end of the camp, youth participated in small focus groups using a semi-structured protocol designed to elicit their feelings about STEM, how they saw themselves in STEM, and whether the camp sparked any desire to pursue further STEM experiences. Pre- and post-surveys consisting of 17 items loosely based on Fennema & Sherman (1976) were implemented to measure changes in attitudes or self-efficacy after completing the camp. Twelve of the items were statements with which participants responded using a Likert scale (1=strongly disagree, 5=strongly agree). Each item had a stem of "I believe I can…" followed by statements such as "do well in science," "do well on an engineering project," and "figure out a solution when I get stuck on a project." The five remaining items were designed to measure intent to pursue with a stem of "I would like to…" followed by statements like "take extra technology courses in high school," "attend more STEM related programs and activities," and "take extra math classes in high school."

DESCRIPTION

The camp was designed to engage females from traditionally underrepresented communities in STEM in unique, non-gendered learning experiences usually not associated with girls in their age group of 9-11 years. From the perspective of the authors, this included realistic engineering hands-on activities that would help youth understand components of complex machines, supporting them to become creators of technology instead of simply consumers of technology (Yu, Chen & Chen, 2019). The camp ran on four consecutive days, from Monday through Thursday, from 10:00am to 3:00pm. Each day, lunch was provided by local restaurants, and a generous donor paid for special T-shirts for the participants.

Monday - Science

> "...science is not as bad as I thought it was and it was actually fun. Because I used to think science was the most boring and dumbest subject I have ever learned but now it's not."
>
> "It affected me by teaching me how to do a experiment with other people. It also made me feel like I could do anything."



Learning about blood typing

During the first activity on Science day, youth learned the basics of blood typing, including understanding which blood types can donate and receive from each other. After informal assessment of their blood type knowledge via the completion of a table illustrating compatible blood transfers, participants used blood typing to solve a "robbery" using the 3B Scientific W56607 Forensic Chemistry of Blood Types Kit. Youth typed synthetic blood and used clues to identify which suspect was the perpetrator. This particular kit is no longer available. However, The Mystery of Lyle and Louise (https://www.schoolspecialty.com/the-mystery-of-lyle-and-louise:-blood-detection-and-evidence-forensics-kit-1385245) offers similar forensic activities, including solving crimes by identifying hair fibers and performing blood splatter analysis.


Solving a mystery

The second part of the day included explanations of chemical reactions and creating bouncy balls using common household items. Participants found the activity fun and satisfying. Understanding that chemistry has material applications seemed to spur further conversations about how materials interact via chemical bonding.

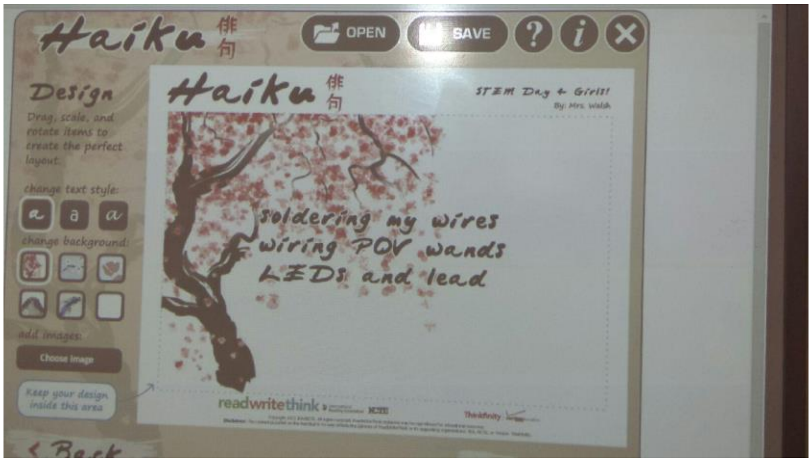

Making a bouncy ball

Tuesday - Technology

> "Soldering was really fun because you got to create something out of something that doesn't seem like would turn into that something."
>
> "The first thing was I learned how to solder and I chose that because it was really fun and it was my first experience."

Instead of learning about circuits using pre-made kits, participants first learned the basics of an atom and electron flow, why some materials are "conductors," while others are "insulators" based on electron mobility. Thus they understood conceptually what a circuit actually is (electrons traveling a closed path) and collaborated to write haikus about the concept.

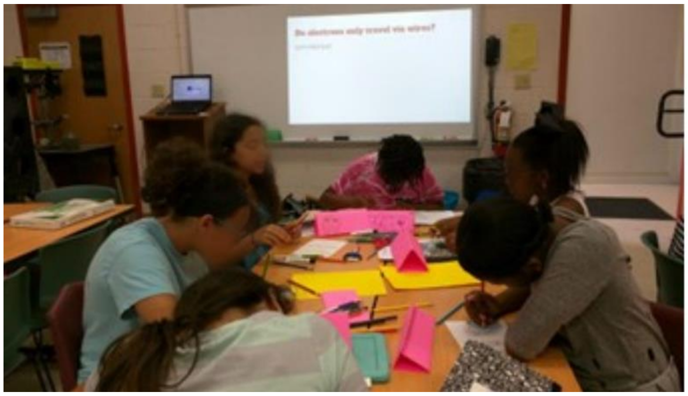

Learning to solder



Soldering haikus

The youth then experienced circuits in increasingly abstracted modalities, starting at the lowest level of abstraction with solder, soldering irons, copper wire, and a power source. After receiving safety instructions, the girls were given time to practice soldering using PCB boards, where they were urged to create patterns until they were able to adequately control the amount and accuracy of the solder. Next, they created persistence of vision (POV) wands, a complex activity that, after connections were successfully soldered, included learning how to program in binary, as well as being introduced to the physical reasons for the phenomenon. Youth had choice in the messages they created with their POV wands, exhibited wonder at the fact that they were actually succeeding at the tedious task of creating a path for electrons to travel by delicate and precise soldering, and showed absolute delight when the lights were dimmed and they were able to spin their wands to read the messages they created with light.

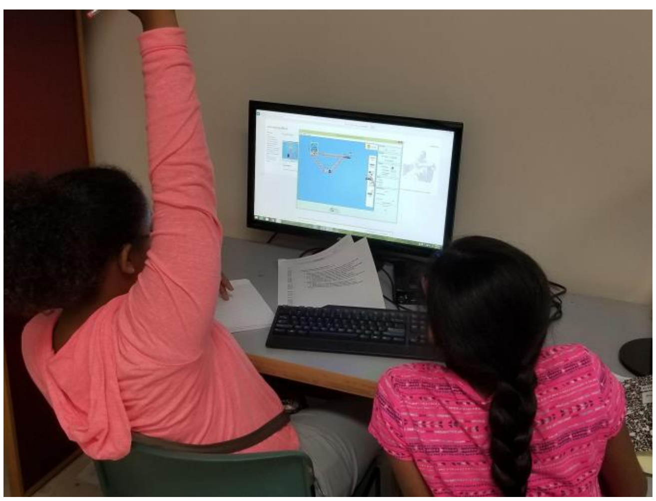
POV Wand in action



Moving from wires to other conductive materials

Next, the girls experimented with conductive paint from Bare Conductive, where they were able to create their own circuit patterns on paper to turn on a light or trigger a sound. This activity built upon the soldering project by illustrating that the basic idea of electric circuits remains the same, whether the conductive material is copper wires or graphite-based paint. Conductive paint gave the participants the freedom to create their own vision of a circuit without being bound by a board or wires.

The youth engaged with a pre-made circuit kit (Elenco Electronic Playground 50-in-One) that came with a book of experiments for them to try, including using saltwater as a conductor. Because the youth had the foundational understanding of what makes a circuit work, they were able to explain why and how some materials worked well and others did not.



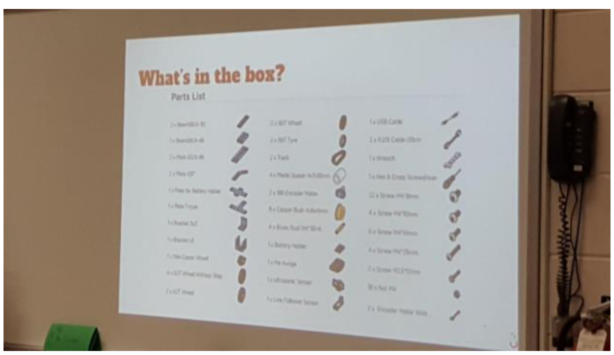
Virtual circuits

Finally, the girls created virtual circuits using the web-based Virtual Lab from PhET Interactive Simulations. Because they knew the difference between reality and simulation, the girls would create increasingly wilder circuits, purposefully overloading lights and catching their creations "on fire." Much laughter ensued with this activity, leading to fierce competition for who could be the most destructive.

Wednesday - Engineering

> "Yes today affect[ed] me to be honest I really didn't wanted to do engineer but today I really like it now and will like to build more stuff in the future hopefully"
>
> "I thought that engineering was just about machines. I now know that its all about craftsmanship and creativity. It requires a true artist to be an [engineer], and a true engineer to be an artist. I think this because we are all different but we made similar products."

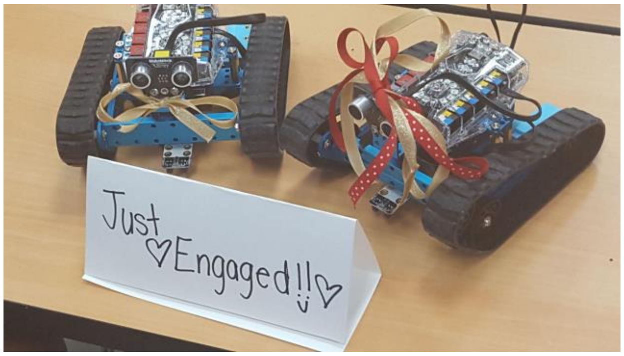
The engineering day was dedicated to the merging of science, technology, engineering, and mathematics by focusing on robotics. Instead of using pre-built robots, participants built robots from MakeBlock kits. The first learning objective for this activity was for the girls to be able to identify all of the parts of the robot before it was built, including the motors and structural elements. To accomplish this, teams of girls were paired with a teen volunteer and inventoried every part in the kit by comparing each to the parts list in the instructions. The participants were told at the start of the activity that they were not only expected to put the robot together, they were also expected to take it apart, re-inventory the parts, and repackage so that the kit could be used again, demonstrating sustainability and responsibility.



Doing inventory


Building the robot

In a completely unanticipated development, the girls, on their own, decided to develop characteristics for their robots, creating two robots named "Rovera" and "Wall-E."



Wall-E and Rovera

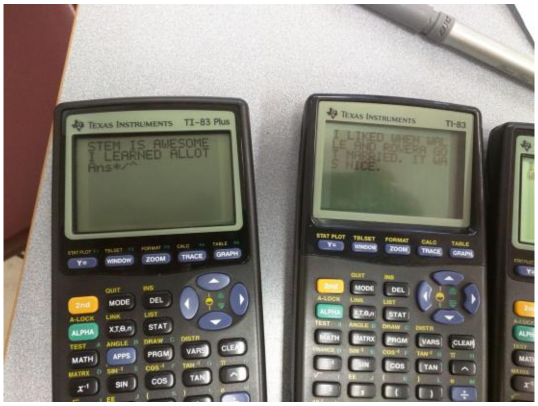
The girls decided to not only develop characteristics for their robots, but also chose to have the robots get "married." They enacted a wedding for them; programming them to walk down the "aisle," and even created original vows. The ceremony was video-taped, edited, and uploaded to YouTube for the girls to watch later. The authors believe that, during the robotics activity, the girls may have started thinking about the male robot character Wall-E. To surface their own gendered identities, they then created a female counterpart robot (Rovera). The availability of various crafting supplies in the classroom space, like ribbon, could have further sparked their creativity.

According to focus group transcripts, this day was the overwhelming favorite for participants. Girls expressed both interest and intent in learning more about robotics, specifically within the context of learning about and creating robots that help people in need. The robotics experience appeared to elicit the most forward-thinking responses in both the presentations and post-camp focus group discussions.

Thursday - Mathematics

> "I think it was really, really fun because…it added challenges."
>
> "I really like to see math. I would like to see more activities. Just like we did."

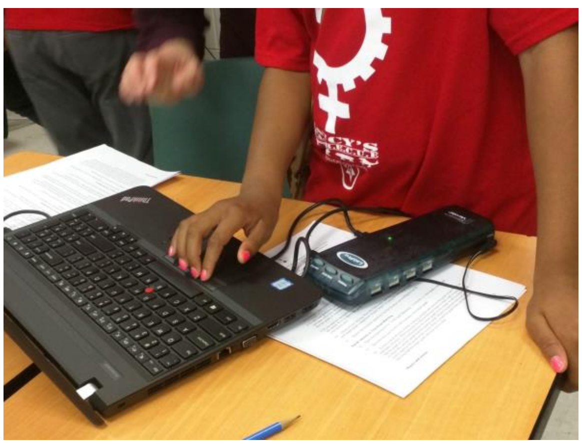
Mobius strips, scientific calculators, and physics were the focus for Mathematics day. As former engineers, the authors feel strongly that mathematics is the foundation for STEM, and that it is imperative that young students see math as not just abstract equations, but the language used to describe relationships in the physical world (Betz & Hackett, 1983; Clapp et al., 2016).



Using calculators to share reflections

In the first mathematics activity, the girls collaborated in small teams to work on logic riddles based on mathematics. Sometimes with a bit of guidance from teen and adult volunteers, teams solved the riddles and showed great excitement at their accomplishments.

For most of the participants, the camp provided their first exposure to graphing (or scientific) calculators. They were shown how to not only graph equations, but write brief reflections about the camp with the calculator. The physical application of equations was demonstrated using widely available science probeware that connects probes to graphing calculators to collect data. The participants attempted to recreate a graph representing acceleration by controlling the acceleration of walking across the classroom. They were very excited to make the connection that mathematics is the language of physics.


Math as the language of physics

It was important to the authors to expand the participants' idea of what "math" is. Toward that end, the authors sought to introduce the concept of a paradox in mathematics through the co-creation of paper mobius strips (e.g., Hongquan, 2001). Once the strips were made, the participants were shown how the concept is used in real world applications like typewriter ribbons, printer cartridges, and conveyor belts.


Creating mobius strips

According to focus group transcripts, this day proved to be the least popular of the days, although a few participants did mention that they discovered new, interesting things about mathematics that they had never thought of before. The authors believe that this day was less engaging because there was less real-life application than the previous days. The first three days also included more making, where the participants had the opportunity to build a working project that performed as a direct result of their effort (e.g., solving a "crime," a blinking artifact, a remote-controllable robot). The authors have learned that the goal of future activities should include ways to demonstrate more direct ties between mathematics concepts and physical or virtual making.

IMPACT

Paired sample t-tests were conducted to compare pre- and post- responses to the self-efficacy and intent to pursue items. Pre-survey (M=4.1, SD=0.4) and post-survey (M=4.3, SD=0.6) responses on STEM self-efficacy items showed a very small non-significant increase ($t(9)=0.6$, $p=0.563$). Results of the paired-t test on responses to the intent to pursue further STEM items indicated that there was a non-significant small difference between Pre- (M=3.6, SD=1) and Post-camp attitudes (M=3.9, SD=0.9), $t(9)=0.6$, $p=.557$.

Qualitative analysis of artifacts and focus group transcripts clearly showed elements of Bandura's self-efficacy framework.

- Fun (emotional arousal)
- Making things work (performance accomplishment)
- Sharing (vicarious experience)
- Encouragement from volunteers (verbal persuasion)

Some sample quotes from each day of the camp are below:

- Science (blood-typing and forensics): "...blood testing that was very fun and I kind of want to be those kinds of people that do that."
- Technology (soldering): "It was fun and, like, just a few wires being attached, you can like make a lightbulb light up."
- Engineering (robots): "I like how you can make it from scratch and not like Legos. We just connected and stuff. You actually had to be creative"

- Mathematics (motion graphing): “Or like trying a challenge and like how to make the graph things you with the sensor. Yeah, it was really fun.”

Focus group transcripts also reveal enthusiasm for STEM subjects, potentially pursuing STEM careers in the future, and an awareness of existing gender stereotypes:

- one by one led me to a direction in my career that I wanted to do. I want to be a scientist and it encouraged me
- inspired me to, like, love all the subjects even more because it taught me, like, a lot of stuff and I enjoyed it.
- I like STEM itself working in a group or like how… kind of working in the group and I kind of made some new friends
- ..thing is these fields that we did the whole week, they're mostly dominated by males, by the boys, by guys because…they're the people that do those kinds of stuff.

There have also been long term effects of the camp on both youth and teen volunteers. Since the first day-long camp in 2014, youth have returned to serve as volunteers themselves and have cited their experiences in the camp as one of the major reasons they pursued higher level STEM coursework in secondary school, or attended college to major in fields like engineering, computer science, and pre-medicine. Former teen volunteers at the camp have credited their opportunity to mentor younger girls in STEM helped them to persist through college to attain degrees in everything from biology (pre-med) and neuroscience to aerospace and mechanical engineering.

An unexpected impact on the teen volunteers was that many of them took initiative to continue STEM outreach to the local community. In fact, for one class of senior technology majors at the high school, these types of activities became part of their coursework. The students developed activities themselves and invited elementary students from the area to experience an afternoon of STEM. The young children learned about concepts like tolerance by participating in a competitive assembly line to create a popsicle stick figure that had to meet specifications. The high school students had also built two augmented reality sandboxes that were one of the highlights for the visiting elementary students. The AR sandboxes were also taken on the road to be part of the US Naval STEM Expo and other exhibitions. Finally, the high school’s robotics team began to hold monthly after-school STEM activities at the community’s public library in partnership with the city’s parks and recreation department.

Although the authors have not tracked most of the participants after the camp experience, one final anecdotal example of long-term impact is when a new freshman at the specialty high school excitedly approached one of the teacher volunteers and asked, “Do you remember me?” The young woman had attended the camp two years before. When the teacher recognized her, the student explained that, while she had decided to focus on art at the high school, she shared, “I am so excited to join the robotics team!”

FUTURE DIRECTIONS

The authors believe that the success of the camp was based on introducing novel, real-world STEM experiences with female adult mentors and teen volunteers who served as aspirational role models for the participants. Daily reflection in the forms of paired presentations and individual journals served as effective feedback for participants, camp volunteers, and organizers. Soldering and Robotics proved to be the most popular activities, most likely because they had the freedom to explore. For instance, the participants were able to create their own POV wand messages and unexpectedly filmed a robot wedding. With these activities, the participants expressed excitement and feelings of accomplishment by building technology from the "ground up" and making it work. As mentioned earlier, the last of the camp focused on mathematics and was the least popular with the participants. The authors believe that mathematics is the foundation for STEM. Moving forward, it is suggested that in future implementations, the design of the camp could be modified to increase mathematics engagement. One option is to make the mathematics inherent during the Science, Technology, and Engineering activities explicit and remove the last day. Another possibility is to use the Mathematics day to continue to introduce mathematics concepts, but also spend time having the participants identify where they believe mathematics concepts were used throughout the other days of the camp.

Although this article was not based on a research study, the authors hope that sharing this experience will help those who wish to offer accessible, meaningful informal STEM experiences to youth. With determination and passion, the authors engaged the community (families, schools, and businesses) to help make this camp happen, and believe that others can do the same.

REFERENCES

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191-215. http://dx.doi.org/10.1037/0033-295X.84.2.191

Bandura, A., & Locke, E. A. (2003). Negative self-efficacy and goal effects revisited. *Journal of Applied Psychology, 88*(1), 87-99. http://dx.doi.org/10.1037/0021-9010.88.1.87

Bettinger, E. P., & Long, B. T. (2005). Do faculty serve as role models? The impact of instructor gender on female students. *American Economic Review, 95*(2), 152-157. http://dx.doi.org/10.1257/000282805774670149

Betz, N. E., & Hackett, G. (1983). The relationship of mathematics self-efficacy expectations to the selection of science-based college majors. *Journal of Vocational Behavior, 23*(3), 329-345. http://dx.doi.org/10.1016/0001-8791(83)90046-5

Clapp, E. P., Ross, J., Ryan, J. O., & Tishman, S. (2016). *Maker-centered learning: Empowering young people to shape their worlds.* John Wiley & Sons.

Coutinho, S. (2008). Self-efficacy, metacognition, and performance. *North American Journal of Psychology, 10*, 165-173.

Fennema, E., & Sherman, J. A. (1976). Fennema-Sherman mathematics attitudes scales: Instruments designed to measure attitudes toward the learning of mathematics by females and males. *Journal for Research in Mathematics Education, 7*(5), 324-326. http://dx.doi.org/10.2307/748467

Fry, R., Kennedy, B., & Funk, C. (2021, April 1). *STEM Jobs See Uneven Progress in Increasing Gender, Racial and Ethnic Diversity*. Pew Research Center. https://www.pewresearch.org/science/2021/04/01/stem-jobs-see-uneven-progress-in-increasing-gender-racial-and-ethnic-diversity/

Hongquan, L. (2001). Exploring math education for girls: How to select materials for mathematics activity classes in girls' middle schools. *Chinese Education & Society, 34*(1), 83-88. http://dx.doi.org/10.2753/CED1061-1932340183

Larose, S., Ratelle, C. F., Guay, F., Senécal, C., & Harvey, M. (2006). Trajectories of science self-efficacy beliefs during the college transition and academic and vocational adjustment in science and technology programs. *Educational Research and Evaluation, 12*(4), 373-393. http://dx.doi.org/10.1080/13803610600765836

Srivastava, A., & Thomson, S. B. (2009). Framework analysis: a qualitative methodology for applied policy research. *Journal of Administration and Governance, 4*(2), 72-79.

Yu, H. P., Chen, H. Y., & Chen, Y. L. (2019, July). The hands-on STEM curriculum design promoting science learning and career self-efficacy for gifted girls. In *Proceedings of the 2019 3rd International Conference on Education and Multimedia Technology* (pp. 225-228). http://dx.doi.org/10.1145/3345120.3345135