An Evaluation of a Pilot Robotics Program

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Abstract

This article presents a program evaluation of a six-week middle school pilot program focused on Science, Technology, Engineering, and Math (STEM) enrichment using robotics, specifically VEX Robots™. Two key questions guided this evaluation: (a) Does exposure to robotics influence middle school dispositions about STEM and careers in STEM? and (b) What lessons can be learned from the experiences of program leaders and students? The aims were to provide guidance and recommendations for future implementation, development, and evaluation of the program. Findings are noted, along with a discussion and recommendations.

Keywords: *Robotics, STEM Education, Middle Schools, Program Evaluation, Adolescence, Equity*

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The benefits of the science, technology, engineering, and mathematics (STEM) fields are known to positively influence economic and social progress (Riegle-Crumb, King, Grodsky, & Muller, 2012). At the individual level, existing literature affirms that STEM careers can influence one's quality of life (Shapiro, Grossman, Carter, Martin, Deyton, & Hammer, 2015; Wiest, Sanchez, & Crawford-Ferre, 2017). It was reported that by 2018, approximately eight million more STEM jobs would be available in the United States (U.S.), a 79% growth since 1990 (Pew Research Center, 2018). According to the Pew Research Center (2018), these STEM positions included healtcare practitioners/technicians, computer workers, engineers/architects, physical scientist, life scientists, and mathematical workers.

Despite the availability of such a wide variety of positions, the majority of students will not be prepared to fill current needs (Teach for American, 2017). Moreover, approximately half (49%) of the public reports that teachers rarely use methods to help students think critically and problem solve, and over two thirds (68%) of postgraduate degree STEM workers have identified this as a problem facing K-12 STEM education (Pew Research Center, 2018). Increasingly, there is a need to focus on developing a strong STEM workforce (Dillivan & Dillavan, 2014). To that end, President Donald Trump signed a memorandum aiming to make STEM a priority for America's schools (Soergel, 2017).

As STEM remains a priority for America's schools, particular emphasis has been placed on exposing students from economically and educationally disadvantaged communities to STEM opportunities. Existing college-readiness program, such as the the federal Gaining Early Awareness and Readiness for Undergraduate Programs (GEAR UP) grant, have worked to provide enrichment opportuntunies for students from low-income family backgrounds to explore the possibility of entering a STEM field (U.S. Department of Education, 2017). Furthermore, exposure to STEM activities can be particularly important for early adolescents, given that gaps in STEM career paths become apparent by at least eighth grade (Hodge, Matthews, & Squires, 2017).

Robotics activities have become a popular avenue used to promote technological fluency and careers in STEM (Cross, Hamner, Zito, Nourbakhshh, & Bernstein, 2016). A focus on robotics can provide students with problem-solving experiences, while also helping students to explore how robotics are connected to the aforementioned STEM jobs. Yet, the ability to implement meaningful STEM programs and activities can be time-consuming and emotionally draining (Soto-Johnson, 2017). Therefore, upon implementation, it is important to gather favorable and unfavorable program aspects in order to better design and implement successful STEM programs (Wiest, Sanchez, Crawford-Ferre, 2017b). Thus, one western state's GEAR UP grant allotted funds to pilot a robotics program across four different middle school contexts. The purpose of this study was to evaluate the pilot robotics program in order to provide guidance and recommendations for future implementation.

Pilot Program Design and Background

Four different formats of the robotics program were piloted for middle school students to determine effectiveness and possible continuation and expansion of the program. The first format was piloted at Middle School 1 and consisted of an in-school effort under the leadership of a non-core academic teacher (agricultural teacher). The second format was at Middle School 2 and consisted of an after-school effort under the leadership of a core academic teacher (science teacher). Similar to Middle School 2, the third format was piloted at Middle School 3 as an in-school effort lead by a core academic science teacher; however, the pilot program was integrated within the science curriculum. The fourth format was piloted at a university's summer program for middle school students as academic enrichment under the leadership of a graduate student. All pilot programs were based on the Carnegie Mellon curriculum, using VEX Robots™; during the pilot efforts, students specifically engaged in building and operating *clawbots* (Vex Curriculum, 2013). Each program lasted six weeks and received support from one university cooperative extension faculty member to guide the implementation during the 2013-14 academic year with the intent to continue the program in subsequent years, as well as expand program offerings to students who participated in the pilot.

Evaluation Design

The researchers volunteered to evaluate the pilot robotics program. Approval was obtained by the university's institutional review board (IRB). The evaluation was guided by two questions: (a) Does exposure to robotics influence middle school dispositions about STEM and careers in STEM? and (b) What lessons can be learned from the experiences of program leaders and students? The evaluation consisted of a pre-post instrument for program participants (middle school students), post-program interviews with pilot program leaders, and post-program interviews with select program participants. Given the small number of anticipated participants in the pilot program, the researchers understood that broad conclusions would not be possible but results could support the local program efforts.

Data Sources and Collection

Two data sources were used for this evaluation: a survey that was administered pre- and post-program and interviews.

Survey. An adapted version of the questionnaire, Students' Motivation Towards Science Learning (SMTSL), by Tuan, Vhin, and Sheih (2005) was used to examine students' beliefs and attitudes about STEM fields. It included 26 questions, using a Likert-type scale (1 = strongly disagree to 5 = strongly agree). The questionnaire was administered before and after students participated in the pilot robotics program. Prior to beginning the survey, students were provided with a one-page cover sheet that defined STEM and listed common STEM school subjects, as well as STEM careers. One of the researchers also discussed the importance of STEM for all students and gave a personal history of STEM career success as a result of post-secondary education.

Interviews. Semi-structured interviews were conducted with two program leaders and six students upon completion of the program. Interview questions for the program leaders focused on how the program was implemented, the challenges they encountered, and recommendations for future implementation. Because it was understood at the outset of the evaluation that the number of survey responses would not allow for robust statistical analyses, student interview questions were designed to gather a more nuanced understanding of student perceptions of STEM and their experiences in the robotics activity. Interviews occurred at the program sites during a pre-arranged time with the program leaders and students. The interviews ranged from 10-20 minutes in length; each interview was audio-recorded and later transcribed verbatim.

Data Analyses

Quantitative and qualitative analyses supported this evaluation. The quantitative analysis focused on responses from the questionnaire. Descriptive statistics were used to gain an understanding of participants and the program implementation. The students' pre-survey responses were examined to assess their initial motivation toward STEM learning. Of note, only 13 students from Middle School 1 responded to the post-survey; post-surveys were not voluntarily completed at the other sites. As a result, only one school site was used to conduct a pre-post analysis; the low sample size of 13 responses serves as a limitation to the quantitative portion of the data analysis, as it leads to questions of reliability and a high margin of error (30%). Therefore, the pre-post analysis should be interpreted with caution.

Analysis of the qualitative data was conducted in two phases: interviews with program leaders, followed by interviews with students. Analysis of the interview data from the program leaders specifically sought how the project was implemented with particular emphasis on the challenges encountered. This approach was intentionally designed to inform future program implementation. Analysis of the interview data from the students aligned with the survey questions to better understand the students' attitudes toward STEM and to capture their experiences with the program. As the interview data were analyzed, emergent codes found in line-by-line analysis were also considered to develop themes.

Survey Statement	*n*	*Mean*	*SD*
I am planning on attending college/university.	94	4.28	.95
I am comfortable working with people different from me.	93	4.25	.80
I believe attaining a STEM degree is worth the effort.	94	4.12	.77
I think that learning STEM is important.	94	3.97	.75
When I make mistakes in STEM classes, I try to find out why.	94	3.97	.77
When learning new STEM concepts, I attempt to understand them.	93	3.96	.69
I take STEM classes to get a higher paying job in the future.	94	3.95	.88
I take STEM classes to get a job with many opportunities.	94	3.94	.93
I take STEM classes to get an important job.	93	3.92	.94
I feel confident about succeeding in STEM classes this year.	93	3.91	.88
I believe I have the ability to complete a STEM major in college/university.	94	3.88	.83
I think STEM is needed to help solve the problems of today.	94	3.84	.87
I feel safe and comfortable in STEM classes and in labs.	94	3.82	.90
I feel supported and encouraged to take STEM classes.	92	3.80	.96
I find the STEM fields to be interesting.	93	3.80	.82
I take STEM classes because I want to learn how to help people.	94	3.79	.88
I feel confident that I will attain a degree in STEM when I go to college/university.	93	3.74	.91
I know how to handle classroom situation in which I feel a lack of support.	93	3.72	.94
I am planning on a career in a STEM field.	94	3.65	.98
I understand how STEM concepts can be used to solve community problems.	94	3.65	.88
I take STEM classes because the content is exciting and fun.	94	3.64	.87
I feel supported and encouraged by my community at large.	94	3.63	.97
I am planning on taking STEM courses as part of my college/university.	94	3.55	.86
I am planning on majoring in a STEM field at a college/university.	93	3.51	.85
I only take STEM classes to fulfill a requirement.*	91	3.01	1.13
When STEM activities are too difficult, I give up or only do the easy parts.*	94	2.33	1.21

Note. *Represents statements that were negatively stated, so a low mean is desirable.

Table 1. Responses to the 26 Statements on a 5-point Scale in Descending Order by Mean

Results

Descriptive Statistics

A total of 94 students who participated in the four pilot programs completed the pre-survey. There were more female (56%) than male (44%) students in the pilot program. Of the 94 participants, one student (1%) was 11 years old, 38 students (40%) were 12 years old, 44 students (47%) were 13 years old, and 11 students (12%) were 14 years old. White and Hispanic students were equally represented at 39% each, along with 12% Native American, 8% mixed race/ethnicity or other, and 2% were non-response; no African American/Black or Asian/Pacific Islander students participated in the program, which was reflective of the schools' demographics.

Survey Statement	N	Pre	Post
I am planning on attending a college/university or tech school in the future.	13	4.38	4.54
I am planning on taking STEM courses as part of my college/university/tech program.	13	3.38	3.46
I am planning on majoring in a STEM field at a college/university/tech school.	13	3.15	3.31

Table 2. Pre-post Means of Statements focused on Planning

The sample size, mean, and standard deviation are provided for all 26 survey items (see Table 1). Altogether, students who completed the needs assessment survey expressed very high expectations for themselves regarding their interest in going to college and participating in STEM.

Pre-Post Test Results

Of the four programs, only 13 participants from Middle School 1 completed both the pre- and post-surveys. A dependent samples t-test was conducted to compare means of the 13 participants in this particular school. Results were statistically significant between pre (Mpre = 3.91) and post (Mpost = 3.71), $t = 3.40$, $df = 25$, $p = .002$). As a cautionary, the low sample size in this analysis yielded a high variation between the participants' responses to the questions and the populations they represented. Interestingly, a different trend in pre-post outcomes was revealed when focused on individual survey items related to future plans (see Table 2).

Interview Findings

Program Leaders

Lack of instructional pedagogy. Two program leaders agreed to participate in interviews upon completion of the pilot program. Interestingly, the program leaders did not view themselves or identify as STEM-focused individuals. Perhaps because of this, their statements centered on their lack of instructional pedagogy for this particular role. Program Leader 1, a graduate student who helped with the university summer program, noted having taken on the position to fill in for someone who had a last-minute schedule conflict. Regarding his experiences with STEM, Program Leader 1 reflected, "Am I like a science person? No, I'm really not." This leader specifically noted that the person tasked with leading the pilot program "should have known a lot more going in" and added, "I should have, I just felt really unprepared." When asked about when and why he had a sense of being unprepared, Program Leader 1 elaborated that, while the focus was on allowing students to problem-solve as they worked to build the robot, he should have engaged in more facilitation: "I was thinking, like, they could do this own their own, but I see now I should have joined in and helped a little bit or to speed up the process."

Program Leader 2 similarly reflected on the process of leading the pilot program. He recalled the decision to spearhead the pilot robotics program and stated, "It was kind of an arm pull;" this leader noted having agreed to implement the pilot robotics program after some gentle nudging and persuasion from the school principal. As one of the "ag" teachers at the school, he taught agriculture and mechanics courses as part of an elective middle school curriculum. Despite his initial reservations, he quickly identified the various ways in which those fields were connected to the pilot robotics program. As a result, he integrated robotics into his course as best as possible to allow for course efforts and the implementation of the pilot program to be aligned and cohesive. Program Leader 2 shared, "But, I mean, the robotics I can see is—in terms of having, like, my background with agriculture, mechanics and that thing, you know, that kinda ties in and so that was interesting to me." In his efforts to connect his own background with the robotics program, he still encountered challenges in implementing the program: "Umm, but when you start to get in depth and, you know, I try to talk about some different concepts with these kids, it just, they just glaze over." He indicated it would have been useful to get more help with different "add-ons" that could assist in various aspects of the pilot robotics program, along with specific activities to make the process more relevant to students.

Structures are a must. Program Leader 1 indicated that he did not think that he would have to provide much guidance because, as part of a summer academic enrichment program, the students would be self-motivated. The leader regretfully added, "I don't think we shoulda necessarily had like all, like, the top kids in the robotics program, just cause how awkward it was. It was, like, so weird." Program Leader 1 shared that students were encouraged to be part of the pilot robotics program because of their high academic achievement. This led to personality struggles within the program, as all of the students wanted a lead role in the process. The program leader noted that it would have been more useful to have designated roles for students, rather than letting students choose/identify their own roles. The program leader added that, due to lack of pre-determined structure and facilitation, students did not accomplish as much as they should have, but "other than that, I think everything else was good. I think the kids really enjoyed it."

Interestingly, while Program Leader 1 noted that diversity in student selection could have helped the pilot program goals, Program Leader 2 noted that students were in the school's robotics pilot program as part of an elective course, which did lead to diversity in academic achievement levels and student interests. Nevertheless, there were still issues. He recalled student differences and noted, "You know, that's kind of, the difficult part of it is. . . I've had some kids that are/were really into it and then some kids that just, they really didn't get into it." Program Leader 2 noted that these class aspects also made it difficult for students to independently design what else to do after building the robot. His solution was to gather information, such as watching YouTube videos, to help students see the end goal, adding, "And that, you know that's kinda good that they can see and then you talk about the gears and the different processes and controls, in addition to the assembling, you know, set-up the robot so. You know, I think that was beneficial as well."

Middle School Students

A fun, first-time experience. All six students who were interviewed noted that they had never built a robot; moreover, they all shared that this was their first experience with robotics in any setting. After noting not ever having thought of building a robot, one student added a common sentiment, "But they were really fun, actually!" Another student recalled having first heard of the opportunity and recalled thinking, "That it was gonna be really fun and exciting." Two of the six students reiterated the fun experience but added some thoughts of concern. One student said, "I was kind of scared 'cause I had no experience with technology, like. . . to build it, I just use it." While some students approached the process with hesitation, each seemed pleasantly surprised with a fun experience.

Overwhelmed but full of pride. All six students shared feelings of being overwhelmed at that beginning of the pilot robotics program. They noted being particularly surprised by the all the parts that were included in the robot-building kit. One student indicated that the robot came with a manual of instructions, "but sometimes we got confused." A different student remarked, "I thought it was gonna be hard cause umm, like the many parts there is, especially how you have to wire it and all the programming." The student went on to share how all the parts and gears worked together and added, "I never imagined a robot being built like this."

While students shared having felt overwhelmed, their statements were interlaced with feelings of pride and accomplishment. One student in particular recalled being "shy" at the start of the program and indicated that, "I kinda outgrew my shell." Another said, "It kind of brought the class together." Yet, another student excitedly shared knocking over a classroom trashcan after searching the Internet to learn how to program and "change the controls on the remote to have them be backwards." The student excitedly remarked, "Yep, it was not that hard. You just gotta figure out how to use 'em. Cause the buttons are backwards." A different student recalled being surprised by having accomplished as much as they did as a group and added, "I would try and see if I could do it by myself" and continued, "I didn't really think we could do anything so unique as that - and special. And get to do it for free, like thousands of dollars of parts."

Real-life, future connections. In thinking about their pilot robotics program, students made statements that referenced future connections in multiple ways. One student stated that he lived on a ranch, wanted to be a veterinarian, and added, "I never really thought of being a, like technology kind of person but this kind of made me [think about that]." Another student indicated wanting to be a doctor and said, "You need science and math." Interestingly, the same student went on to reference a computer elective class as being related to the pilot robotics program and said that math was a favorite subject. It was noteworthy, however, that the student did not explore how science might be related to robotics. A different student indicated being in algebra and added that doing this program, "It probably gives me an opportunity to take some engineering class [sic], so I'm ready for some other real-life situations." One of the students similarly focused on real-life situations. The student likened the pilot robotics program to problem-solving with other science and technology experiences. For example, the student shared having helped at church with a malfunctioning sound system and later helping the father with the boiler that was "giving us cold water." The student went on to share a love of music and art, but reflectively asked, "How am I supposed to get any money with that?"

Discussion

By the sixth grade, students from economically and educationally disadvantaged communities may have missed as much as 6,000 hours of enriching learning opportunities as compared to students from middle class families (ExpandED Schools, 2013). It remains critical to narrow this gap, particularly though STEM enrichment opportunities. Existing literature identifies elementary and middle school as an important time to attract students into STEM fields (Maltese & Tai, 2010). The pilot robotics program in this evaluation aimed to support this need for students in GEAR UP, who were middle school students and from low-income family backgrounds.

Robotics experiences can be important for students, as they have been shown as a tool not only for hands-on learning but also to engage in many STEM topics (Matarić, Koenig, & Feil-Seifer, 2007). Furthermore, the materials used to support students' experiences should be creative, accessible, and affordable (Matarić et al., 2007). Findings from this evaluation indicated that the two program leaders who were interviewed wished they had more background knowledge in STEM; ultimately, their lack of instructional pedagogy made it challenging to creatively implement the program and expand the use of materials provided. This finding supported Matarić et al.'s (2007) argument that educators need "ready-for-use lesson materials" for hands-on experiences with robotics (p. 1).

In addition, the pedagogical experiences of instructors should be considered as a necessary qualification prior to the program implementation. This is particularly important because strengthened teaching methods can benefit all students (Jobe 2002/2003). For example, Laursen, Hassi, Kogan, and Weston (2014) found that inquiry-based learning in mathematics resulted in greater student leadership and students asking more questions. Thus, these strengthened strategies that attend to the importance of the STEM experience for students, as well as the pedagogical experience for the instructors, can bring further meaning to the educators and result in positive outcomes for students.

Both program leaders also identified a need for further structure within the program. Specifically, they contended that strategies related to student inclusion could help to better diversify the participants and their experiences. One leader's comment explicitly pointed to some conflicts among students who all had high achievement levels, which was consistent with Olszewski-Kubilius, Lee, and Thomson's (2014) report that empirical evidence supports the view that academically advanced students may be more socially awkward and at-risk for adjustment problems. The other program leader identified variation in commitment among students. Soto-Johnson (2017) similarly reported applicants' lack of commitment as a program challenge. Erchick (2017) found program barriers with multiple strong personalities in groups and noted that staff guidance and facilitated reflections could help enhance group dynamics; however, she also recognized that short program durations can make it difficult to resolve such situations. Thus, the pilot robotics program leaders' experiences were not uncommon to this type of work, so professional development in classroom management could help to strengthen program implementation efforts in a proactive manner.

Despite the programmatic challenges, students' experiences provided a level of optimism about the pilot robotics program. None of the students had previous experience with hands-on robotics, which demonstrates students had a clear need for enrichment and exposure to STEM. Moreover, students seemed to genuinely enjoy the experience and had "fun" in the pilot robotics program. In other words, students seemed to have been meaningfully engaged with the robotics experience; this is an essential component to the education process. Along with reporting their positive engagement, students admitted having felt scared or overwhelmed by the process (or robotics parts). Still, students experienced a sense of pride in themselves and/or as a group. These positive dispositions remain important, particularly as dispositions toward STEM continue as a key focus in similar programs and their respective evaluations (Wiest et al., 2017).

It must be noted that students' mean ratings (pre-post) were statistically significant with overall lower mean values after having completed the program. One explanation could be that students understood STEM more clearly after completing the program and, therefore, provided more realistic ratings than before the program. When examining students' specific planning perspectives toward STEM by survey item, however, these ratings seemed to align with their ability to make future connections, although we approach both findings with caution, given the low sample size. Certainly, long-term outcomes remain unknown, but Soto-Johnson (2017) argued that her program "situates the participants to be successful in a STEM career, if they choose to pursue such a field" (p. 21), which is a valuable consideration.

Recommendations and Practical Implications

From a programmatic evaluation perspective, incentivized efforts for increased interview and survey participation would have helped. Only two of the four program leaders and six students participated in interviews. In addition, more post-survey responses would have helped to conduct pre-post analyses to augment the program evaluation. Also, despite the varied school settings (in school or out of school), it was made clear that the leaders who are tasked with implementing STEM programs should have specific instructional pedagogy in this area. This can facilitate the implementation process, provide strengthened enrichment opportunities and guidance to participants, and enhance the overall program experience for everyone involved. More strategic efforts in finding educators with the appropriate fit to lead such a focused program is a critical feature to consider. Once the appropriate appointment of a program leader is made, those tasked with launching a program should be available for follow-up and support, such as in-person guidance and/or with materials, including structured timelines, implementation tools or manuals, strategies for methods and pedagogy, classroom management skills, and student selection models for diversification. As was the case in these pilot robotics programs, neither leader felt they had sufficient information to appropriately facilitate the program efforts but did their best to ensure the program was carried out. It is important to highlight, however, that students did not appear to have known about the leaders' hesitations or concerns with program implementation. Also, while students felt overwhelmed with the initial experience, it was clear that they were meaningfully engaged, enjoyed the pilot program, and reflected on the field of STEM, its possible careers, and how STEM understandings translated into daily experiences. Students who shared their experiences provided a lens into positive dispositions toward STEM and their future planning.

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