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Fundamental: Analyzing the Effects of a Robotics Training Workshop on the Self-efficacy of High School Teachers

Mr. Abhidipta Mallik, New York University

Abhidipta Mallik received his B.Tech. degree in Electronics and Communication Engineering from the West Bengal University of Technology, Kolkata, India, and M.Tech. degree in Mechatronics from the Indian Institute of Engineering Science and Technology, Shibpur, West Bengal, India. He has one year and ten months of research experience at the CSIR-CMERI, India. He is currently a Ph.D. student in Mechanical Engineering at NYU Tandon School of Engineering, Brooklyn, NY, where he is serving as a research assistant under an NSF-funded ITEST project.

Dr. Sheila Borges Rajguru, New York University

Dr. Sheila Borges Rajguru is the Assistant Director at the Center for K12 STEM Education, NYU Tandon School of Engineering. As the Center's STEM Educator and Researcher she works with engineers and faculty to provide professional development to K12 science and math teachers. In addition, she conducts studies that looks at embedding robotics and technology in K12 schools. As a former Adjunct Professor at Teachers College, Columbia University and biomedical scientist in Immunology, Dr. Borges balances the world of what STEM professionals do and brings that to STEM education in order to provide PD that aligns to The Next Generation Science Standards (NGSS). Since 2008 she has provided teacher PD to science teachers in the tri-state area, including international visiting teachers and scholars. Dr. Borges' research interests include: building STEM professional-teacher relationships, diversity and equity, and enhancing urban science teaching and learning.

Dr. Vikram Kapila, New York University

Vikram Kapila is a Professor of Mechanical Engineering at NYU Tandon School of Engineering (NYU Tandon), where he directs a Mechatronics, Controls, and Robotics Laboratory, a Research Experience for Teachers Site in Mechatronics and Entrepreneurship, a DR K-12 research project, and an ITEST research project, all funded by NSF. He has held visiting positions with the Air Force Research Laboratories in Dayton, OH. His research interests include K-12 STEM education, mechatronics, robotics, and control system technology. Under a Research Experience for Teachers Site, a DR K-12 project, and GK-12 Fellows programs, funded by NSF, and the Central Brooklyn STEM Initiative (CBSI), funded by six philanthropic foundations, he has conducted significant K-12 education, training, mentoring, and outreach activities to integrate engineering concepts in science classrooms and labs of dozens of New York City public schools. He received NYU Tandon's 2002, 2008, 2011, and 2014 Jacobs Excellence in Education Award, 2002 Jacobs Innovation Grant, 2003 Distinguished Teacher Award, and 2012 Inaugural Distinguished Award for Excellence in the category Inspiration through Leadership. Moreover, he is a recipient of 2014-2015 University Distinguished Teaching Award at NYU. His scholarly activities have included 3 edited books, 9 chapters in edited books, 1 book review, 61 journal articles, and 140 conference papers. He has mentored 1 B.S., 26 M.S., and 5 Ph.D. thesis students; 47 undergraduate research students and 11 undergraduate senior design project teams; over 480 K-12 teachers and 115 high school student researchers; and 18 undergraduate GK-12 Fellows and 59 graduate GK-12 Fellows. Moreover, he directs K-12 education, training, mentoring, and outreach programs that enrich the STEM education of over 1,000 students annually.

Fundamental: Analyzing the Effects of a Robotics Training Workshop on the Self-Efficacy of High School Teachers

1. Introduction

The *Next Generation Science Standards* (*NGSS*) are national standards developed by educators, teachers, and scientists across the nation to address and enhance science, technology, engineering, and math (STEM) education [1]. Its 3D model includes Science and Engineering Practices (SEPs), Disciplinary Core Ideas (DCIs), and Cross Cutting Concepts (CC's), which gives teachers guidelines on how to address natural phenomena across all science disciplines [1]. NGSS highlights the importance of including science and engineering practices in K-12 classrooms. However, teacher certification and professional development (PD) programs require significant support to facilitate integration of engineering and technology in K-12 schools [2]. Prior research focusing on the use of robotics in STEM education has explicitly acknowledged the challenge of teacher preparation [3]. For example, lack of teacher training has been identified as one of the main challenges preventing the adoption of robotics in K-12 STEM education [4]. Teachers often find it difficult to link robotic activities to curriculum outcomes [5]. Thus, it is evident that the sustainability of robotics-based activities in K-12 STEM education is strongly tied to the quality of teacher PD programs. Because teachers have limited knowledge in engineering and robotics concepts, this directly affects student learning and creates a workforce in the U.S. that is not prepared to address the millions of jobs that require knowledge and mastery of engineering practices. As noted recently, the U.S. has lost its rank in top 10 countries for scientific innovation [6]. The lack of teaching engineering disciplines in K-12 classrooms is a major contributor to this decline.

Teachers are the gatekeepers of education. However, many teachers report having low self-efficacy in their ability to teach science, which in turn affects students' science learning [7]. Self-efficacy is the belief in one's ability to "organize and execute courses of action required to deal with prospective situations that contain many ambiguous, unpredictable, and often stressful, elements" [8]. The development of self-efficacy relies on four key components [9]:

- performance accomplishments: when individuals experience direct success;
- vicarious learning: wherein learning results from observing successful peers perform tasks, also known as modeling;
- verbal persuasion: led by verbal persuasion that an individual can perform a task; and
- emotional arousal: anxiety filled situations can weaken confidence, therefore efforts to reduce anxiety is vital for strong self-efficacy.

When all four components are addressed, teachers develop strong self-efficacy. Alternatively, when teachers have low self-efficacy in science they do not believe that they can learn the science content, do not trust their abilities to teach science, and do not trust that their students are capable of learning science. Self-efficacy encompasses nuanced issues and for the purposes of this study we will focus on teachers' self-efficacy in learning concepts in engineering and robotics by addressing all four components.

To address teacher self-efficacy, we designed a hands-on, summer STEM PD workshop. Our effort included the development of an NGSS-aligned robotics curriculum, its delivery and refinement during the PD workshop, and observing and documenting how teachers enacted the curriculum with their students. Researching teachers' attitudes and beliefs about the importance of robotics and technology [3] are critical factors in PD programs. Along with self-efficacy, teachers' knowledge of the disciplinary content is correlated to their students' learning gains [10]. In this study, we investigated teachers' robotics self-efficacy and content knowledge as they learned robotics and whether our robotic PD workshop was effective in increasing their self-efficacy and understanding of content principles. As described later in the paper, the student participants are to support their teachers during the follow-up, academic year implementation of the robotics curriculum in schools. In a future study, we will examine the effects of the PD workshop on participating students' learning. Moreover, in another future study, we will report on teachers' enactment of the curriculum.

Our PD workshop was a four-week summer program consisting of a two-week guided training and a two-week collaborative robotic-product development. The workshop was attended by 18 teachers and 33 high students from 10 high schools in New York City and neighboring regions. This paper is devoted to analyzing the self-efficacy and content learning outcomes for the teachers of our PD workshop. Our goal is to continue providing STEM education to teachers and students for years to come. Thus, it is important for us to evaluate our PD workshop so that we can improve our performance in the years to come. For all these reasons, analyzing the teachers' self-efficacy with respect to robotics design and robotics knowledge become necessary. Surveys and a technical quiz are used to examine whether the PD workshop contributes to any changes in the teachers' self-efficacy, familiarity, and knowledge *vis-à-vis* robotics. We posit that teachers' exposure to learning hands-on and minds-on robotics will increase their self-efficacy and have an impact in their teaching and students' learning. A complete description of the workshop content, hands-on activities, and full analysis of survey and technical quiz results are provided in the subsequent sections of the paper.

2. Professional Development Structure

The PD workshop was a four-week summer program consisting of a two-week guided training and a two-week collaborative robotic-product development. The workshop was attended by 18 teachers and 33 students from 10 inner-city high schools located in an urban environment. The PD workshop was held at the NYU Tandon School of Engineering (SoE) under the Innovative Technology Experiences for Students and Teachers (ITEST) program of the U.S. National Science Foundation. Teachers and students attended the robotics workshop at the engineering school to learn side-by-side with each other. The project team included engineering and education faculty, post-doctoral researchers, and graduate and undergraduate engineering students who collaborated on the preliminary design, pilot testing, implementation, and assessment of the PD program. There were six engineering students (four graduate and two undergraduate) who served as facilitators responsible for delivering the lectures and supervising the hands-on learning sessions. The racial makeup of the facilitators was as follows: four Asians, one White, and one African American. All of the facilitators had expertise in robotics through their education or research experiences.

For our PD workshop, we used the VEX Robotics Clawbot kit [11] (see Figure 1), Arduino UNO microcontroller, motors, wheels, gears, and sensors such as infrared (IR), light dependent resistor (LDR), ultrasonic, push buttons, etc. Building a robot using this kit is easy, making the kit ideal for learners. All robot programming was done using the Arduino IDE [12]. The Arduino language consists of a set of C/C++ functions that can be called from the Arduino code as needed. The Arduino IDE's editor page is used to write the Arduino program called a "sketch." The Arduino environment transforms the sketch into a C++ program through pre-processing that slightly modifies the sketch, e.g., by adding automatically generated function prototypes. Following the pre-processing, the resulting code is compiled using a C/C++ compiler (avr-g++). The Arduino environment supports various C/C++ programming constructs that work with avr-g++. See Ref. [12] for additional details on the Arduino build process.

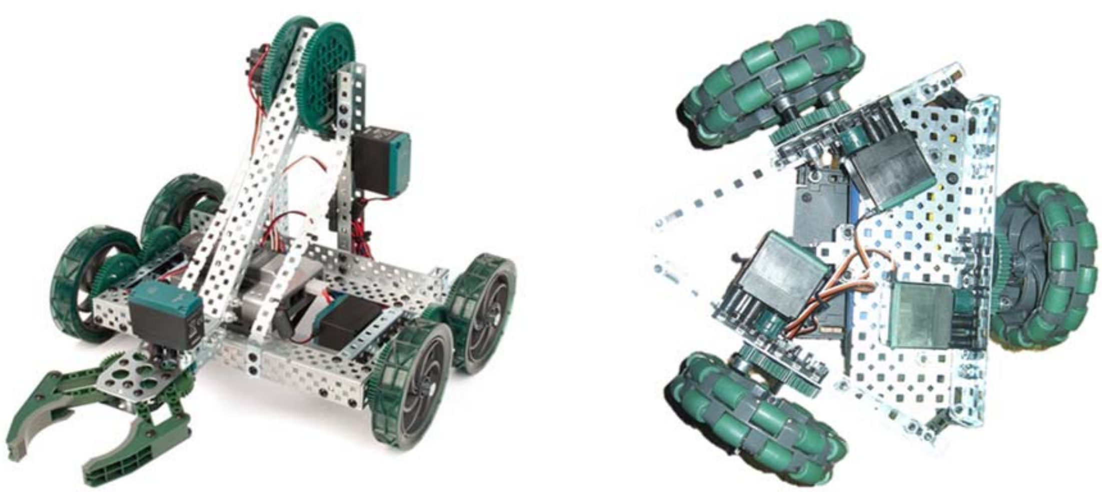


Figure 1: VEX educational robotics kit

3. Curriculum Development

The curriculum of the program was designed following careful deliberations among the project team members. It required consideration of two competing criteria. First, being aware that for most participants this PD workshop will constitute their first experience in robotics, we developed hands-on robotics lessons for novice learners. Second, to develop a scientifically and technologically sound workforce with authentic experiences and understanding of robotics, we created lessons that covered both the foundational and practical elements of robotics. After extensive consultations and iterations, we prepared a thorough curriculum and training strategy. The objective was to have a comprehensive robotics course such that the participants could make most of the four weeks of the of the PD. We strived to make the environment congenial and suitable for learning.

a) Guided learning

The first two weeks of PD workshop were dedicated to teaching and guided learning through structured projects. Each day of the first two weeks consisted of morning and afternoon sessions. Four hours of each session were roughly split into one hour of foundational learning in the form of lectures and notes and the remaining three hours for structured, hands-on learning activities. For the hands-on activities, participants worked in groups consisting of two teachers and three to four students. For each hands-on activity, we designed and used worksheets containing the underlying fundamentals of the session's lesson, some preliminary exercises, and instructions to do the hands-on activity. We started with a lesson on "Introduction to Robotics" with the purpose of motivating the participants to be enthusiastic about robotics. As part of the corresponding hands-on activity, participants constructed the chassis of their mobile robot on the first day.

Over the next few days, the participants learned about Arduino programming, robotics, electrical and electronics components, sensors, motors, 3D printing, etc. [13-17]. Following each theoretical lesson, participants performed corresponding practical activities. Below we provide illustrative examples of topics covered in three lessons and the corresponding hands-on activities.

In the lesson on motors, participants learned about different types of motor such as DC motor and servo motor and their uses. The lesson included topics such as: working principle of DC motors, technique of pulse width modulation (PWM) consisting of a series of pulses with varying width (i.e., on time), use of PWM method to control the speed of a DC motor, and design and operation of a bridge circuit for efficiently altering the direction of rotation of a DC motor, among others. An integrated circuit (IC) L293D, with a built-in bridge circuit, was introduced to interface an Arduino with a DC motor to change its speed and direction of rotation under program control. The lesson concluded by highlighting to participants the precautions they need to take when interfacing a DC motor with the Arduino using the L293D IC (e.g., using separate power sources for the motor *versus* the Arduino). For the hands-on session corresponding to the motor lesson, participants were provided a worksheet in which the basic motor concepts were reiterated so that participants had opportunity to review them. Next, in a simple exercise, they were asked to compute the duty cycle and power for several given PWM signals. For the first experimental activity, participants interfaced a 2-wire VEX motor using the L293D IC to an Arduino and programmed it to control the speed and direction of the motor. As a final experimental activity, the participants performed direction and speed control of a 3-wire servo motor after calibrating it. Figure 2(a) shows participants building a Clawbot for this activity.

(a) (b)

Figure 2: Participant engaged in hands-on actives (a) participants building a Clawbot and (b) participants working on the first project

The lesson on drive mechanisms for mobile robotics discussed topics such as basics of drive mechanisms, various types of drive mechanisms (e.g., differential, holonomic, skid, swerve, crab, and Ackermann) including their pros and cons, types of wheels such as omnidirectional and Mecanum, and Cartesian and polar coordinates. Throughout the lesson, various videos were shown to demonstrate and clarify concepts about drive mechanisms. For the hands-on activity, participants worked on building, assembling, and programming their Clawbot which had a differential drive. They programmed the robot to move in the forward and backward directions as well as to make it turn by a user-specified angle in the right and left direction. To allow participants to develop independence, in this activity we did not provide any step by step instructions. Instead, we directed them to recall their learning from the prior lesson on DC motor control and build on it to perform the hands-on activity of this lesson.

The lesson on sensors began with an explanation for the need for sensors, varied uses of sensors, different sensor types, and operating principles of sensors such as IR, LDR, and ultrasonic. The electrical schematic for interfacing these sensors with Arduino and reading their output using Arduino programs were also discussed. Measurement terminologies such as accuracy, resolution, sensitivity, repeatability, and precision were also discussed. For the hands-on, experimental activity, participants first used an LDR to turn an LED on-off and then they controlled the LED brightness using the LDR.

Although all lessons were critical, the lesson on motion and dynamics for mobile robotics was of paramount importance. This lesson was a milestone because building on this lesson participants were able to program their robot to move from one place to another. See Appendix A for curriculum details and schedule of implementation.

b) Robotics projects

In the last two weeks of the PD workshop, participants worked on two different projects. In the first project, participants were supposed to build a line following robot. This robot was to retrieve 'cups' from a particular location in the arena created for the project. They had to retrieve all the cups on the game field, except one cup called the 'forbidden' cup that the robot should not attempt to retrieve. The position of the forbidden cup was dictated by the project team just before the participants assembled to perform the retrieval task and it was different for different groups. The method to distinguish the forbidden cup from the other cups was an open-ended problem left to the participants. That is, the participants were free to modify the cups in any manner to help distinguish the forbidden cup from the other cups. For example, the color of the forbidden cup could be made different from the other cups, so that a color sensor might be used to identify the forbidden cup. Similarly, a sensor and a corresponding physical phenomenon could be used to identify the forbidden cup (e.g., using a buzzer-sound sensor pair or a magnet-Hall effect sensor pair, etc.). This project was similar to a real-life scenario where robots need to pick and deliver objects from one place to another while rejecting hazardous objects and this generated much interest among the participants. Figure 2(b) shows the participants working on the first project.

For the second project, the project team came up with a real-world plantation/gardening scenario [18]. For managing a nursery, farm, or garden, plants are often grown in containers that are organized in a grid pattern. As the plants grow in size, the containers need to be moved around to prevent the plants from getting damaged. Moreover, the size of available space may dictate the number of columns or rows in the grid occupied by the containers. Inspired by this situation, we came up with a project where the participants were to imagine 10 cups, as 10 plants, placed in a single column at a certain location in the arena. The primary task of the robots was to retrieve the cups and place them on specified locations in a specified row-column grid with specified gap between the cups as illustrated in Figure 3. The challenge captures the situation as if the small plants separated closely in the nursery have grown and the big plants need more space between them to develop properly.

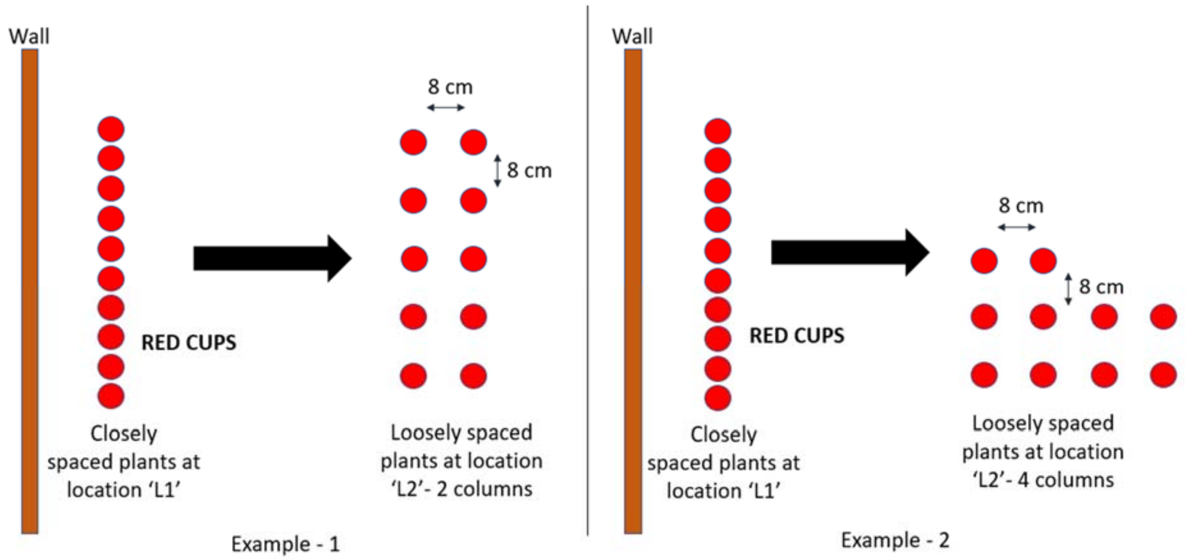


Figure 3: Second project schematic

During the academic year, the participating teachers are to conduct a robotic course and a capstone robot design project for students of their school. The high school students who attended the summer PD workshop are to help the teachers in the class because effective implementation of robotics activities in classrooms needs significant human resources.

4. PD Workshop Objectives

The objectives of our PD workshop were as follows. We aimed at integrating robotic fundamentals and hands-on activities under Project Based Learning (PBL) to increase participants' STEM self-efficacy. We sought to enhance teachers' capacity to engage students in robotics through PBL. Helping in teachers' approaches to address students' fear of failure and lack of confidence and their strategies to promote students' creativity, flexibility, collaboration, and communication skills were other objectives. In addition, we sought to provide professionalization and partnership opportunities to engineering students, faculty, and industry. Throughout the curriculum development, we aimed to formulate robotics activities under PBL that would help participants to learn content and thinking strategies and foster their higher-order cognitive skills. Moreover, through the use of PBL, we expected to address participants' fear of failure, lack of confidence, and creativity and communication skills.

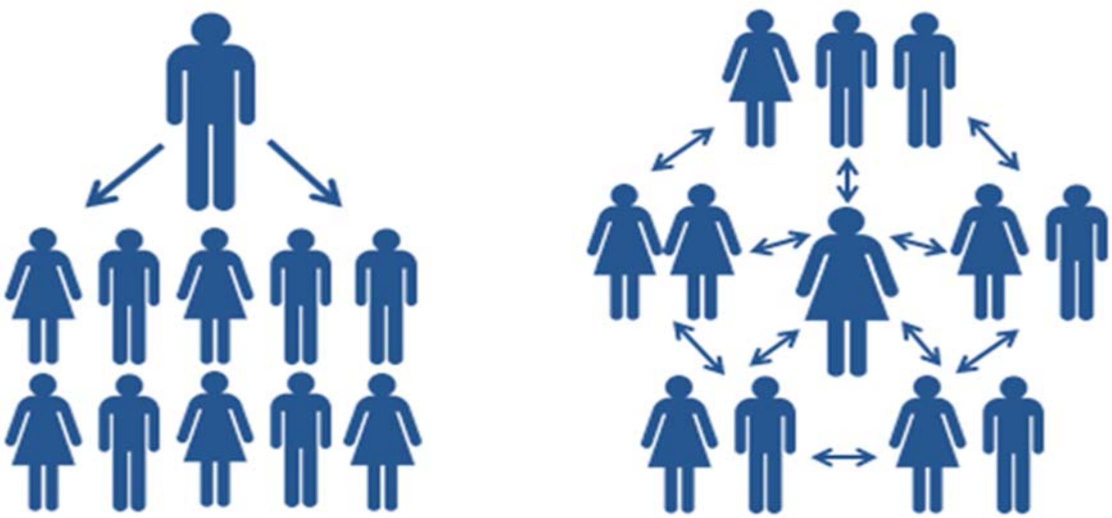
As for the benefits of the PD workshop for participants, we anticipated that effective PD would support transfer of training through content-immersion, allow modeling and rehearsing of desired skills, last for sufficient duration to handle cognitive demands of new learning, and facilitate classroom adoption through a professional learning community (PLC). To achieve our objectives, we incorporated evidence-based strategies from research on PBL and robotics. Moreover, we integrated lessons from prior research on robotics [19-21] in STEM education and social cognitive career theory [22] to examine the construct of self-efficacy.

5. Project-Based Learning Model

PBL is a pedagogical approach where gains in knowledge and skills take place as students work to investigate and respond to an authentic, engaging, and complex question, problem, or challenge [23]. The PBL model consists of several steps [24] as shown in Figure 4. First, teachers need to activate students' prior knowledge [24] by formulating and launching a project that engages student interest and promotes questioning. Usually, a good driving question [23,24] captures the essence of the project in precise, compelling language, which gives students a sense of purpose and challenge. To ensure that the project is deemed meaningful by the students, careful consideration must be given to their lived experiences. This allows students to have their own voices and choices [24], promoting their buy-in and participation. A worthy project must engender opportunities for students to experience and hone such 21st century skills as collaboration, communication, critical thinking, and the use of technology [24,25]. PBL engages students in real inquiry [23] that begins with the students posing question, generating hypothesis, seeking resources to find answers, framing new questions, exploring and testing ideas, and formulating conclusions [24]. Formalizing a process for feedback and revision [24] during a project makes learning meaningful since it emphasizes that creating high-quality products [23] and performances is an important purpose of the endeavor. Students answer questions and reflect on how to complete the project, next steps they need to take, and what they gain in terms of knowledge, skills, and pride. The role of a teacher is vital for the implementation of PBL in classroom environment. As Figure 5(a) shows, the teacher's role is of a facilitator where she motivates students, keeps them engaged, and supports them by providing feedback. To strengthen the projects, as in Figure 5(b), students need to work on the feedback they receive from their teacher and members of the other teams. In short, the main objectives of PBL are as follows [23-25].

- Highlight relevance of disciplinary content through engaging projects to engender student interest and promote self-discovery of knowledge.
- Capture the core of the project in a clear, compelling language and provide students a sense of purpose.
- Promote skills development, e.g., collaboration, communication, critical thinking, and decision-making.
- Engage students to formulate their own questions and seek answers, leading to testing and validation of creative ideas.
- Provide feedback and encourage revision, make learning purposeful, and produce high-quality products.
- Reflect on types of skills students developed and plan for the scope of future activities.

Figure 4: The PBL cycle



(a) (b)

Figure 5: The PBL implementation (a) teacher as facilitator and (b) feedback from others

6. Research Procedure

This paper is devoted to analyzing the outcomes of the robotics PD workshop *vis-à-vis* teachers. Teachers had expertise in math or science. Their demographic and discipline information is given in Table 1 below.

The analysis and results presented below are based on two survey instruments and a technical quiz that align with the lessons delivered in the workshop. Each of the surveys and technical quiz was conducted once at the start of the workshop and then again on the last day of the workshop. One survey compared pre-/post-workshop self-efficacy of teachers regarding robotics design. Specifically, the robotics design self-efficacy survey focused on the mental aspects of an individual (e.g., his/her confidence, anxiety, etc.), in performing robotic design, testing, etc. Using the second survey, we determined pre-/post-workshop changes in the familiarity level of teachers with commonly used robotics concepts and devices. Finally, using the technical quiz, we established pre-/post-workshop changes in the content knowledge of teachers about robotics.

Table 1: Demographic and discipline information of the teachers

	Gender			Race					Subject	
Teachers (18)	Male	Female	Other	White	African American	Hispanic	Asian	Other/ Mixed	Math	Science
	10	7	1	8	4	1	2	3	6	12

Survey 1—Robotics design self-efficacy

To determine each teacher's self-efficacy before and after the robotics PD, a survey was designed by appropriately adapting the self-efficacy instruments from Refs. [26,27] to make it suitable to the nature of our PD program. The self-efficacy survey consisted of 36 questions with the aim of quantifying changes in teachers' confidence, motivation, success expectation, and anxiousness *vis-à-vis* their will to persist and skill to succeed. The questions on this survey are given in Appendix 2.

Self-efficacy refers to the belief in one's ability to successfully complete a task [28]. It includes individual's perception about his or her ability to plan and implement a course of action to successfully complete the task [29,30]. We see variations in efficacy levels in people in same fields and at the same time there is variation in areas in which people cultivate their efficacy [28]. Self-efficacy is goal oriented [31] and the self-efficacy assessments include directing respondents to rate their level of confidence for attaining a specific goal [28].

As engineering design occupies a central place in the education, training, and practice of engineers [32], students' self-efficacy in engineering design can influence their learning of engineering itself [26]. This is also true for robotics education wherein robotics design tasks are integral to learning about robotics. Similar to the engineering design tasks [26], applied and practical aspects of robotics constitute the robotics design tasks and may necessitate consideration of individual components, subassemblies, and integrated systems to fulfill design specifications. Self-efficacy studies in engineering design tasks also include quantifying and analyzing differences in the self-efficacy held by individuals with a range of engineering experiences. Prior studies on self-efficacy in engineering design tasks have also examined how the self-efficacy values differ with gender and background of the participants [27,33].

In this effort, our focus was to measure the change in self-efficacy values before and after the training with the objective of improving our PD. For this reason, we did not consider any gender and background related studies, instead we performed a generalized study. This survey had four sections for rating an individual's perceived confidence, motivation, success expectation, and anxiety in performing several portions of the project-based robotic design. These portions included conducting robotic design, identifying robotic need, researching a robotic design need, developing robot design solutions, selecting the best possible robot design, constructing a robotic prototype, evaluating and testing a robot design, communicating a robot design, and redesigning a robot if required.

Survey 2—Familiarity with robotics

Through this survey, we determined pre-/post-workshop changes in the familiarity level of teachers with commonly used robotics concepts and devices. All the instructional and structured learning parts of this PD workshop (e.g., mechanism, electrical and electronics, sensing, actuation, data acquisition, and programming) were quite important as they helped in building a foundation for applying a systematic approach to problem solving. To further pique and stimulate the participants' interest in the PD program's learning activities, experimental demonstrations of a variety of educational and research projects were given to them. The guided training component of the program introduced participants to the foundational elements of robotics: for example, sensors, actuators, electronics, electromechanical components, and microcontrollers. The lectures covered the topics listed in Appendix 1 and the structured project activity for each session's corresponding lecture included clearly stated objectives with a sequence of steps to be followed. Based on the topics covered in guided learning, Survey 2 of Appendix 3 included 21 questions.

Robotics technical quiz

Teachers' ability to sustain learned knowledge was examined through their individual performance on a technical quiz on the topics and concepts delivered to them through lessons and hands-on activities. This quiz had 30 questions on robotics lessons with sections such as robot drive mechanism, electronics, localization and mapping, and gears and motors. To permit reuse of the technical quiz in the future offerings of this PD workshop, we are unable to share its contents.

These teachers are expected to deliver robotics education to their students all through the academic year. Thus, all the aforementioned analyses were necessary to establish any benefits engendered through the PD workshop. Based on the result of this initial study, further research will be performed to alter and enhance the content, structure, and organization of the PD workshop to improve its future offerings.

7. Results

Survey 1—Robotics design self-efficacy

For anxiety-related questions (Q28-Q36), teacher responses were reverse scored for analysis purposes. Pre-and post-survey results show an improvement in overall self-efficacy from a mean value of 58.97 to 68.63 on a scale of 100 (see Table 2). Figure 6 shows a bar graph, where each bar is the average response for all 18 respondents, comparing each of the 36 questions for the teachers. Note that for a few questions there is a drop in post-program self-efficacy value, specifically the drop is for the questions on motivation. However, this drop is negligible compared to the improvement in other questions. A paired-sample *t*-test analysis was also performed to test the null hypothesis, i.e., if $\mu_{before} = \mu_{after}$ (within the rejection limit), where μ_{before} and μ_{after} are the mean pre-test and post-test scores. Table 3 shows the results of this analysis. We obtained a t value of 2.657. From standard *t*-test tables, for 95% confidence level with 17 d.f., a two tail t distribution necessitates a t value of 2.110 or higher. Thus, at 95% confidence level, our result is significant and we reject the null hypothesis. Table 3 also provides Cohen's d [34] as 0.733, indicating a medium effect size of the treatment on participants' self-efficacy.

Survey 2—Familiarity with robotics

We compared the pre- and post-test values of the familiarity with robotics survey by plotting a bar graph, where each bar is the average response for all 18 respondents. The difference of the familiarity level for individual questions is compared in Figure 7. In this bar graph we see improvement in familiarity for all the questions. Pre-and post-survey results show that there has been an improvement from a mean value of 1.74 to 3.37 on a scale of 5. Next, in Figure 8, we compare the pre-/post-project familiarity with robotics for individual teachers, where each bar is the average response for all 21 questions by an individual respondent. Note that for only three participants there has been a drop in the post-project survey response. However, the drop is less than one on a scale of five. Moreover, as noted above, in Figure 7 for all questions there was an improvement seen in the post-project response *versus* the pre-project response. For this reason, we ignore the negative result we obtained for three individuals in Figure 8. Next, we performed a paired-sample *t*-test analysis and found the t value as 4.729 which is more than 2.110 for 95% confidence level and is in the rejection region (see Table 3). The corresponding p value for the two tail test is 0.00019. Thus, we reject the null hypothesis. Table 3 also provides Cohen's d as 1.57, indicating a very large effect size of the treatment on participants' familiarity with robotics.

Table 2: Self-efficacy survey pre-/post-test results

n	Pre-test		Post-test	
	Avg.	Std. dev.	Avg.	Std. dev.
18	58.97	13.39	68.63	12.97

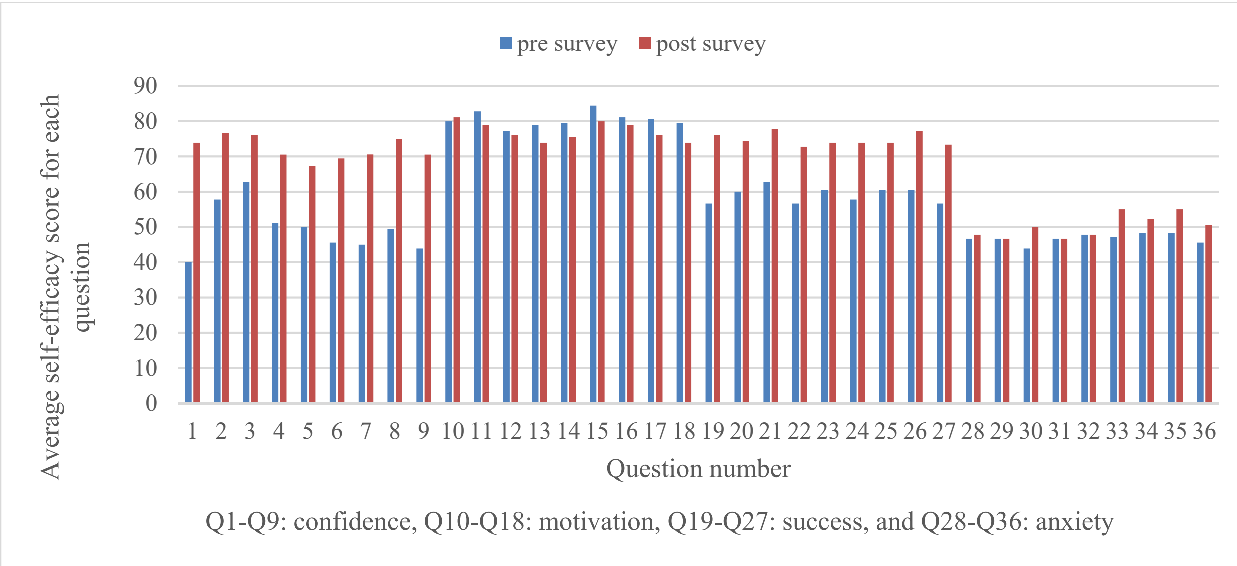


Figure 6: Pre-/post-survey responses to robotics self-efficacy instrument

Table 3: Results of *t* tests and Cohen's *d* for the two surveys and the technical quiz

	Scale	Pre-test average	Post-test average	*n*	*t*	*p*	Significance	Cohen's *d*
Self-efficacy	100	58.97	68.63	18	2.657	0.0166	Yes @ 95%	0.733 (medium)
Robotics familiarity	5	1.74	3.37	18	4.729	0.00019	Yes @ 95%	1.57 (very large)
Technical quiz	30	14.39	18.17	18	2.686	0.0156	Yes @ 95%	0.99 (large)

Robotics technical quiz

From Table 4 we see that there has been an improvement in teachers' performance with average performance increasing from 14.39 to 18.16 (26.25% increase). Next, we performed a paired sample *t*-test that yielded the *t* value as 2.686 which is more than 2.110 for the 95% confidence level and is in the rejection region (see Table 3). The corresponding *p* value for the two tail test is 0.0156. Thus, we reject the null hypothesis. Table 3 also provides Cohen's *d* as 0.99, indicating a large effect size of the treatment on participants' content knowledge.

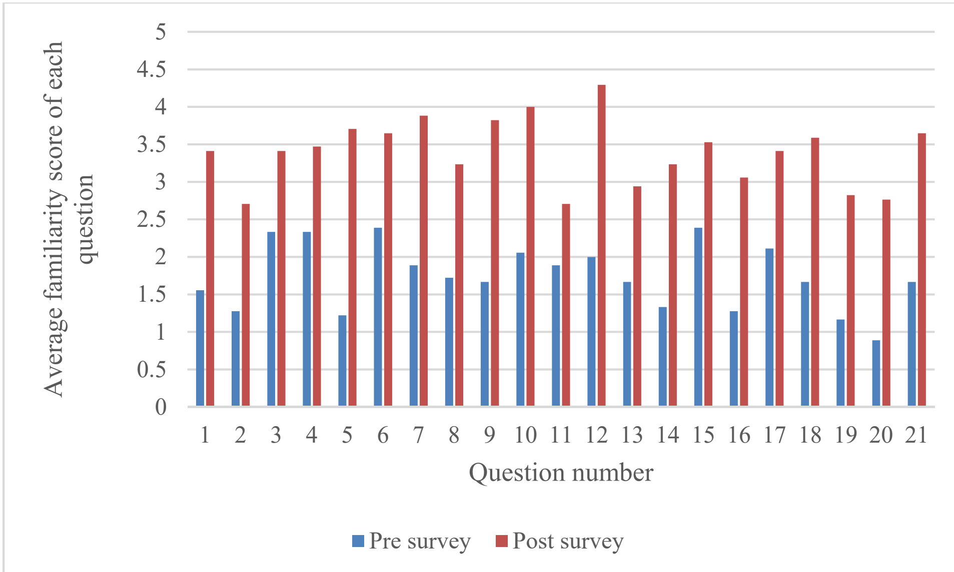


Figure 7: Pre-/post-survey responses to robotics familiarity survey for individual questions

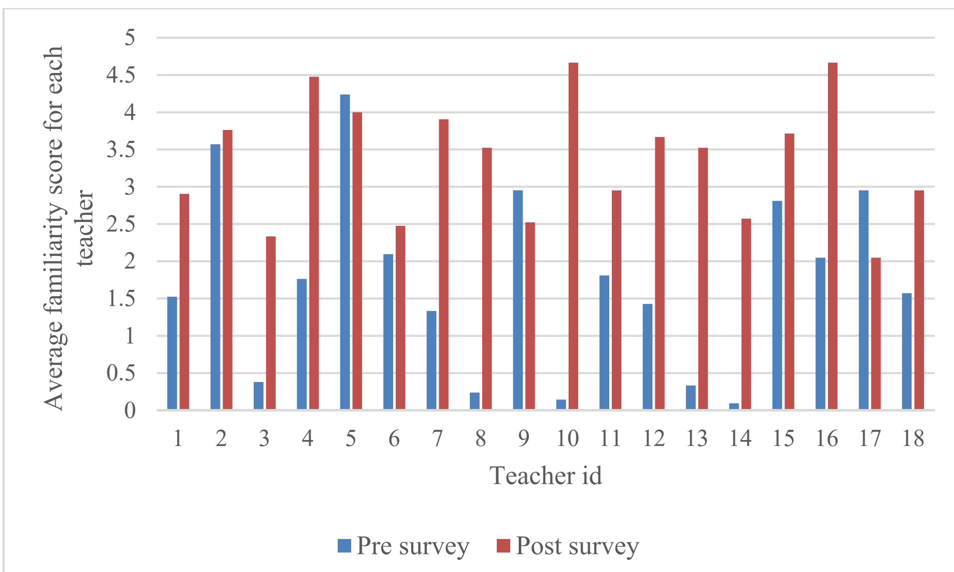


Figure 8: Pre-/post-survey responses to robotics familiarity survey for individual respondents

Table 4: Technical quiz comparison

	Mean	Std. dev.	Max	Minimum
Pre	14.39	3.55	20	6
Post	18.17	4.03	26	9

8. Discussion and Future Work

Although the U.S. has new national science standards, limited studies have investigated the implementation of the NGSS' SEPs. Our study is vital to STEM educators and PD providers as it outlines the challenges and success of implementing a robotics curriculum for science and math teachers, along with the investigation of teachers' self-efficacy. As evidenced below, the PD workshop allowed participants to complete open-ended robot design projects by learning from their engineering instructors while performing collaborative hands-on activities and overcoming anxiety, all of which contributed to the components of self-efficacy (e.g., performance accomplishment, vicarious learning, and emotional arousal), which is shown to increase from pre- to post-tests. The pre- and post-survey results show overall improvement in the teachers' robotics self-efficacy, familiarity with robotics devices, and average score on the technical quiz. For example, results illustrate a 94% increase in teacher's familiarity with robotics with pre-test average of 1.74 increasing to the post-test average of 3.37 (out of 5). Moreover, results show a 26.25% increase in teachers' knowledge of technical robotics content with pre-test average of 14.39 increasing to the post-test average of 18.17 (out of 30).

To contribute to participants' sense of ***performance accomplishment***, they were engaged in varied hands-on learning activities that allowed them to experience success while overcoming obstacles. During the PD workshop, hands-on activities in the beginning were of low to moderate difficulty that grew to be of moderate to high difficulty toward the end. With this approach, as participants tasted quick initial successes in completing hands-on activities, it piqued their interest and contributed to the growth in their self-efficacy. This was done purposefully so that participants develop strong self-efficacy because early stage failures can negatively impact self-efficacy. Gradually with practice and instructor feedback participants became comfortable with our curriculum and by the beginning of third week most of them were able to shed any initial reservations they might have had. As engineering educators, we continued to reflect upon the project and participants' performance to improve their learning. For example, whenever participants faced challenges in conceiving and implementing solutions for the projects, instructors offered scaffolds to enable the participants to complete the project tasks. Specifically, sample mechanical assembly diagrams, circuit schematics, programs, and one-on-one tutorials were included in the beginning, however such scaffolds became unnecessary and were slowly removed as participants' confidence grew. Throughout the PD workshop, participants performed robot building, electronic integration, robot programming, and robot operation and suggested alternative approaches to authentic, open-ended robotic projects, gaining significant ability in performing hands-on teaching and learning successfully.

Unlike performance accomplishments, ***vicarious learning*** is achieved when participants view their peers achieve mastery or effectively perform a given task. To support this component of self-efficacy's social learning theory, participants who struggled were given the opportunity to observe their fellow participants succeed in the hands-on activities. These successful participants modeled how to perform tasks thereby influencing the expectations of their non-successful counterparts. For example, during the guided training phase of the workshop, we observed that while some participants exhibited excitement when new concepts and tools were introduced in lectures they displayed hesitation in getting started with hands-on activities due to their concern about misidentifying electronic components, making the wrong electrical connection, or damaging the microcontroller and other components (emotional anxiety). Members of the project team (i.e., the instructors and senior personnel), regularly monitored the participants' activities and engagement to identify those who were experiencing challenges and those who were successfully completing assigned tasks. Next, we encouraged the successful participants to serve as models by demonstrating their work and collaborating with and supporting those needing assistance. Seeing high school students and other participants be successful in challenging robotics tasks enabled participants to envision being persistent and successful themselves.

Most participants were engaging in a robotics PD workshop and working at an engineering school for the first time. Thus, it was natural for them to feel nervous, especially during the first week of the PD. To counteract participants' ***emotional arousal*** (e.g., anxiety), the project team vigilantly monitored their verbal and non-verbal behaviors while they worked on the projects. As indicated above, some participants were concerned about making mistakes during the hands-on learning activities and in fact some of them became demotivated when they inadvertently damaged electronic components. To allay their anxiety, the instructors interacted with them one-on-one to identify the source of their error, encouraged them to learn from their mistake, and asked them to plan and complete the same task correctly. As the participants experienced success in completing hands-on activities, it contributed to the growth in their self-efficacy score in the anxiety section.

An area of future study is to target the component of ***verbal persuasion***, the verbal affirmation that an individual can master or complete assigned task. We note that there was a drop in the motivation section of the robotics self-efficacy survey. One reason for this may be because we integrated motivational talks, i.e., verbal affirmations of participants' abilities, only in the first few days of PD. Following daily reflections, instructors decided to incorporate additional motivational talks during the project activities. Moreover, our observations indicate that the participants' motivation level improved after the motivational talks were enacted. Nonetheless, the post-test results for motivation level are lower than for the pre-test. Thus, it is possible that the project in the last week was particularly challenging for participants and led to the decline in their motivation. In future offerings, we will seek to address this problem by offering more verbal affirmations so that participants do not feel demotivated.

The four components of self-efficacy intricately provide the stimulus for a strong self-efficacy. When one component is not fully developed, as the component of verbal persuasion in this study, participants do not reach full potential of learning gains. This research adds to existing literature by analyzing the process of implementing SEPs in a robotics curriculum and the effects on teachers' self-efficacy. Further research will be performed to alter and enhance the content, structure, and organization of the curriculum and PD to improve its effectiveness. The structured experiments illustrated and reinforced the material covered in the lectures and allowed for further exploration. From the quiz results and self-efficacy results, we deduce that self-efficacy is a significant predictor of task performance. Higher STEM self-efficacy performance implies better and longer persistence in STEM disciplines. This is because STEM self-efficacy predicts academic performance beyond one's ability or previous achievement, since confident individuals are motivated to succeed. The current study focused only on teacher participants. A similar study can be conducted with students as well. Future studies can investigate how teachers implement these lessons with their students focusing on the NGSS' DCIs and CCs. In addition, future studies can analyze the effects that academic and professional backgrounds and gender have on participants' robotics design self-efficacy and performance. Though these preliminary results show that the PD was successful, there is room for improvement. Based on the feedback we received from participants, we will modify the curriculum so that we can improve the PD workshop in future offerings.

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References

1. NGSS. Online: https://www.nextgenscience.org. Website of Next Generation Science Standard. (2017).
2. Kelley, T.R., and Wicklein, R.C. "Teacher challenges to implement engineering design in secondary technology education," *Journal of Industrial Teacher Education*, 46.3 (2009): 34-50.
3. Vollmer, U., et al. "Teachers need robotics-training, too," Automation, Communication and Cybernetics in *Science and Engineering*, (2011): 359-364.
4. Mataric, M.J., Koenig, N.P., and Feil-Seifer, D. "Materials for enabling hands-on robotics and STEM education," *Proc. AAAI Spring Symposium on Robots and Robot Venues: Resources for AI Education*, (2007): 4 pages.
5. Norton, S.J., McRobbie, C.J., and Ginns, I.S. "Problem solving in a middle school robotics design classroom," *Research in Science Education*, 37.3 (2007): 261-277.
6. Jamrisko, M., and Lu, W. "The U.S. Drops Out of the Top 10 in Innovation Ranking" 2018. https://www.bloomberg.com/news/articles/2018-01-22/south-korea-tops-global-innovation-ranking-again-as-u-s-falls.
7. Palmer, D., Dixon, J., and Archer, J. "Changes in Science Teaching Self-Efficacy among Primary Teacher Education Students" *Australian Journal of Teacher Education*, 40.12 (2015): 27-40.
8. Bandura, A. "Self-efficacy mechanism in human agency" *American psychologist*, 37.2 (1982): 122.

9. Bandura, A. “Self-efficacy: toward a unifying theory of behavioral change.” *Psychological review* 84.2 (1977): 191-215.
10. Tschannen-Moran, M., Woolfok-Hoy, A., and Hoy, W.K. “Teacher efficacy: Its meaning and measure,” *Review of Educational Research*, 68.2 (1998): 202-248.
11. VEX Educational Robotics. Online: https://www.vexrobotics.com. Website of VEX robotics. (2017).
12. Arduino Microcontroller. Online: https://www.arduino.cc. Website of Arduino microcontroller. (2017).
13. Arduino Microcontroller Tutorial. Online: https://www.arduino.cc/en/Tutorial/HomePage. Website of Arduino microcontroller tutorial. (2017).
14. Petre, M., and Price, B. “Using robotics to motivate ‘back door’ learning,” *Education and Information* Technologies, 9.2 (2004): 147-158.
15. Siegwart, R. *Introduction to Autonomous Mobile Robots,* Cambridge, Mass: MIT Press. (2011).
16. Tinkercad Tutorial. Online: https://www.tinkercad.com/learn. Website of Tinkercad tutorial. (2017).
17. Whitaker, J.C. *The Electronics Handbook,* Florida: CRC Press. (2005).
18. Harvey: A working robot for container crops. 2013. Online: http://robohub.org/harvey-a-working-robot-for-container-crops. Website of Harvey robot.
19. Benitti, F.B.V. “Exploring the educational potential of robotics in schools: a systematic review,” *Computers & Education*, 58.3 (2012): 978-988.
20. Riojas, M., Lysecky, J., and Rozenblit, J. “Educational technologies for precollege engineering education,” *IEEE Transactions on Learning Technologies,* 5.1 (2012): 20-32
21. Reich-Stiebert, N. and Eyssel, F. “Robots in the classroom: What teachers think about teaching and learning with education robots,” *Proc. International Conference on Social Robotics,* (2016): 671-68
22. Lent, R.W., Brown, S.D., and Hackett, G. “Social cognitive career theory,” *Career Choice and Development,* 4 (2002): 255-311.
23. Kokotsaki, D., Menzies, V., and Wiggins, A. “Project-based learning: A review of the literature,” *Improving Schools,* 19.3 (2016): 267-277.
24. Larmer, J., and Mergendoller, J.R. “7 Essentials for project-based learning,” Educational Leadership, (2010): 34-37.
25. Musa, F., Mufti, N., Latiff, R., and Amin, M. “Project-based learning (PjBL): Inculcating soft skills in 21st century workplace,” *Procedia - Social and Behavioral Sciences,* 59 (2012): 565-573.
26. Carberry, A., Ohland, M., and Lee H.S., “Measuring engineering design self-efficacy,” *Journal of Engineering Education*, 99.1(2010): 71-79.
27. Igel, I., Poveda, R. L., and Kapila, V. “Examining the efficacy of a LEGO robotics training for volunteer mentors and K-12 teachers,” *Proc. ASEE Annual Conference and Exposition*, (2012). https://peer.asee.org/21355.
28. Bandura, A. “Self-efficacy: toward a unifying theory of behavioral change,” *Psychological Review*, 84.2 (1977): 191.
29. Bandura, A. “The explanatory and predictive scope of self-efficacy theory,” *Journal of Social and Clinical Psychology*, 4.3 (1986): 359-373.
30. Bandura, A. “Guide for constructing self-efficacy scales,” *Self-efficacy Beliefs of Adolescents*, 5 (2006): 307-337.
31. Bandura, A., and Locke, E.A. “Negative self-efficacy and goal effects revisited,” *Journal of Applied Psychology*, 88.1 (2003): 87-99.
32. Dym, C.L., Agogino, A.M., Eris, O., Frey, D.D. and Leifer, L.J. “Engineering design thinking, teaching, and learning,” *Journal of Engineering Education*, 94.1 (2005): 103-120.
33. Listman, J. B., and Kapila, V. “Gender-specific effects of a summer research program on STEM research self-efficacy,” *Proc. ASEE Annual Conference and Exposition*, 10.18260/p.2540. (2016).
34. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*, USA: Lawrence Erlbaum Associates. (1988): 19-44.

Appendix 1: Guided Training Curriculum

Lesson (Session)	Contents	Activities and Tasks
1. Introduction to robotics (Day 1, AM)	History, fundamentals, components, types, illustrative commercial applications, and motivational videos.	Introduction to and use of electrical, mechanical, structural components in VEX EDR robotics kit, Arduino microcontroller, sensors starter kit etc.
2. Structure and chassis construction for mobile robotics (Day 1, PM)	Physics concepts (forces, momentum, equilibrium, stability, center of mass/gravity); robot types (manipulator, mobile, aerial, under-water); chassis components, construction (with design tradeoffs), and functions of mobile ground robots; videos to illustrate varied chassis configurations and designs.	Construction and assembly of VEX ClawBot chassis and installation of electrical components (motors, bread board, microcontroller, etc.) onto the ClawBot chassis.
3. Electronics primer for mobile robotics (Day 2, AM)	Basic electrical and electronic components (conductors, insulators, resistors, capacitors, batteries, switches, diodes, LEDs, speakers, motors) and laws (Ohm's law, voltage-current relations, series/parallel networks); analog and digital signals; digital logic (Boolean algebra, logic gates); breadboarding (use, instructions, safety).	Hands-on introduction to electrical and electronic components (resistor, capacitor, switch, multi-meter); blinking LEDs using with push-button control; LED manipulation using logic gates and potentiometer.
4. Introduction to Arduino (Day 2, PM)	Arduino UNO anatomy; installation and setup of Arduino IDE; writing, compiling, and uploading code using the Arduino IDE; a simple first program to blink LEDs under program control	Interface five LEDs to the Arduino and light them in a predefined sequence or simultaneously; interface a pushbutton to Arduino and sense its state; control the on-off state of an LED under program control by sensing pushbutton state; sense the state of a LDR to control the brightness of an LED.
5. Motors and servos for mobile robotics (Day 3, AM)	Introduction to electric motors (types, operations, use); direction control of DC motors (bridge circuits, L293D IC); speed control of DC motors (pulse width modulation); interfacing and controlling servos using Arduino (position, speed, and direction control).	Finding duty cycle and power for given PWM signals; direction and speed control of VEX 2-wire motors using L293D IC; calibration and position, direction, and speed control of a 3-wire servo motor.
6. Motion and dynamics for mobile robotics (Day 3, PM)	Basic concepts of physics and mechanics (distance, displacement, speed, velocity, acceleration, friction, inertia, mass, weight, torque, scalars and vectors, radius, diameter, revolution, circumference); types of motion in robotics (linear, oscillatory, periodic, circular, uniform, non-uniform); inertial and non-inertial reference frames; laws of motion, Newton's law of gravity; introduction to gears and pulley (types, parameters such as dimensions, teeth, pitch, gear ratio, motion reversal, idler); speed vs torque tradeoff.	Calculating gear ratio, gear reduction, output torque, output speed for given gearing parameters and VEX 2-wire motor specifications; effect of gear configuration on robot speed and torque; selecting gear combination to achieve desired speed and torque for a specific task.

7. Arduino basic programming (Day 4, AM)	Arduino environment; communicating with a serial monitor; arithmetic operations; conditional operators; loops; binary-decimal conversion; pull-up and pull-down concepts.	Beginner-level programming, e.g., communicating with serial monitor and programs with loops.
8. 3D printing for robotics (Day 4, PM)	History, concepts, and applications of 3D printing; state-of-the-art 3D printing machines; introduction to TinkerCAD.	Creating a 3D model of an object with specified dimensions and shape in TinkerCAD.
9. Revise and reiterate build and programming tasks (Day 5, AM)	Allow time for participants to revise and reiterate various build and programming tasks from prior lessons and activities.	Revision of prior hands-on activities.
10. Drive mechanisms for mobile robotics (Day 5, PM)	Basics of drive mechanisms (wheels, turn types and points, turning scrub): types of drives (differential, holonomic, skid, swerve, crab, and Ackermann); types of wheels (omnidirectional, Mecanum); Cartesian and polar coordinates.	Program a to move forward and backward a specific amount of distance and turn by a specified angle.
11. Sensors for mobile robotics (Day 6, AM)	Uses, types, operation modes (active, passive, analog, digital), working principles, terminology (accuracy, resolution, sensitivity, repeatability/precision).	Use a light dependent resister to turn an LED on-off and control the LED brightness.
12. Arduino programming to acquire sensor data (Day 6, PM)	Basics of: sampling theorem, bandwidth, moving average (MA) filter, sensor polling, interrupts on Arduino, interrupt service routine, timer interrupts, and noise removal.	Blinking LED with push button switch using polling and external interrupts; measuring tilt angle using accelerometer by understanding specification from the sensor’s datasheet.
13. Arduino advanced programming (Day 7, AM)	Programming syntax, data types, variables, and constants; control structures (for, while, do while, if-elseif-else, switch case, break, continue, return, nested loops); operators (comparison, Boolean, bitwise, compound, binary).	Write a program to detect obstacles using an ultrasonic proximity sensor; create an autonomous grasping program for the ClawBot.
14. Line following robot (Day 7, PM)	Basics of line following for mobile robots; types of line following sensors (IR, LDR); operating principle; and specifications.	Program the Clawbot so that it follows a path created using a black colored marker/tape (applied to a white background).
15. Robotic arms, Grippers, and end-effectors (Day 8, AM)	Basics of robotic arm, degrees of freedom, joints, links, robot configuration, different grippers and gripping mechanisms.	Complete building the line following robot and have it pick up and manipulate objects.
16. Revise and reiterate build and programming tasks (Day 8, PM)	Allow time for participants to revise and reiterate various build and programming tasks from prior lessons and activities.	Revision of prior hands-on activities.
17-20. Entrepreneurship (Days 9 and 10)	Business planning (business model canvas); market analysis (product market matrix, Porter’s 5 forces, and technology S-curve); product development process; raising capital (venture capital, crowd funding, alliances grants etc.); startup incubators; managing intellectual property; social entrepreneurship.	Experiential learning by creating and presenting a pitch for a new venture.

Appendix 2: Robotics Design Self-efficacy Instrument [26]

Please enter your self-assigned four-digit identification number: _______________

DIRECTIONS: Please answer all of the following questions fully by selecting the answer that best represents your beliefs and judgment of your current abilities. Answer each question in terms of who you are and what you know today about the given tasks. (0 = low; 50 = moderate; 100 = high)

Q1-Q9: Rate how <u>confident</u> you would be to perform the following tasks by checking a number from 0 to 100.

	0	10	20	30	40	50	60	70	80	90	100
Perform robotic design											
Identify a robotic design requirement											
Research a robotic design requirement											
Develop a robot design solutions											
Select the best possible robot design											
Construct a robotic prototype											
Evaluate and test a robot design											
Communicate a robot design											
Redesign a robot											

Q10-Q18: Rate how <u>motivated</u> you would be to perform the following tasks by checking a number from 0 to 100.

	0	10	20	30	40	50	60	70	80	90	100
Perform robotic design											
Identify a robotic design requirement											
Research a robotics design requirement											
Develop a robot design solutions											
Select the best possible robot design											
Construct a robotic prototype											
Evaluate and test a robot design											
Communicate a robot design											
Redesign a robot											

Q19-Q27: Rate how <u>successful</u> you would be to perform the following tasks by checking a number from 0 to 100.

	0	10	20	30	40	50	60	70	80	90	100
Perform robotic design											
Identify a robotic design requirement											
Research a robotic design requirement											
Develop a robot design solutions											
Select the best possible robot design											
Construct a robotic prototype											
Evaluate and test a robot design											
Communicate a robot design											
Redesign a robot											

Q28-Q36: Rate how <u>anxious</u> you would be to perform the following tasks by checking a number from 0 to 100.

	0	10	20	30	40	50	60	70	80	90	100
Perform robotic design											
Identify a robotic design requirement											
Research a robotic design requirement											
Develop a robot design solutions											
Select the best possible robot design											
Construct a robotic prototype											
Evaluate and test a robot design											
Communicate a robot design											
Redesign a robot											

Appendix 3: Familiarity with Robotics Concepts

DIRECTIONS: Please answer all of the following questions fully by selecting the answer that best represents your beliefs and judgment of your current abilities. Answer each question in terms of who you are and what you know today about the given questions.

Rate your level of familiarity with each area listed (0 = not familiar, 5 = very familiar)	1	2	3	4	5
Robotics design					
Robot drive mechanisms (e.g., differential, holonomic, swerve, etc.)					
Physics concepts (e.g., force, momentum, friction, equilibrium, etc.)					
Center of mass/center of gravity					
Building a robot chassis					
Voltage, current, and resistance					
Resistors					
Variable Resistors					
Sensors: Ultrasonic, accelerometer, light dependent resistor					
Light emitting diodes (LEDs)					
Capacitors					
Breadboard					
Boolean algebra					
Serial communication					
Binary numbering system					
Digital/analog signals and conversion					
Programming logic					
Microcontroller					
Pulse width modulation (PWM)					
H-bridge					
DC Motors					