Analysis of Student Self-Efficacy During an Integrated, Life-Centered Robotics Learning Experience

Abstract

In 2018, the U.S. Federal government published a STEM education strategy report outlining a vision with three goals (building a strong foundation for STEM literacy, increasing diversity, equity and inclusion in STEM, preparing the STEM workers for the future) for providing Americans access to high-quality STEM education and acquisition of future workforce skills (National Science & Technology Council, 2018). This report identified a quality STEM education for American students as one solution with the potential to meet this challenge. In an effort to support the 2018 federal STEM education initiative, this study was designed to evaluate the impact of student engagement in an integrated STEM unit on self-efficacy. Specifically, this research reports on the impact of an integrated robotics educational unit developed within a life-centered context that appealed to underrepresented populations on the level of student Engineering and Design self-efficacy.

Participants in this quasi-experimental, one-sample study included 30 seventh-grade students from a suburban middle school. Once participants completed the unit, individuals responded to the Engineering Skills Self-Efficacy Instrument (ESSE) in a retrospective pretest and a posttest. Gain scores for each student were analyzed with one-sample *t*-tests and Kruskal-Wallis tests. The one-sample *t*-test results indicated a significant gain in all constructs of the ESSE. The Kruskal-Wallis analysis displayed no significant difference between minority and majority groups indicating an equitable learning experience for all. The integrated learning experience impacted student self-efficacy and provided an equitable unit where all students could develop knowledge and skills.

Keywords: best practices, robotics education, integrated STEM, self-efficacy

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Introduction

In response to an increase in science and technology occupations, the U.S. Federal government outlined a vision in 2018 with three goals to provide Americans access to high-quality science, technology, engineering, and mathematics (STEM) education to increase the knowledge and skills of the future workforce (National Science & Technology Council, 2018). The three goals include 1) building a strong foundation for STEM literacy; 2) increasing diversity, equity, and inclusion in STEM; 3) preparing the STEM workers for the future (National Science & Technology Council, 2018). Within the vision, transdisciplinary learning was identified as a method to meet these goals by combining teaching and learning across multiple disciplines and requiring learners to create solutions to authentic challenges (National Science & Technology Council, 2018).

Transdisciplinary learning shares many similarities with integrated STEM education in that integrated STEM education encompasses a variety of experiences possessing some degree of connection between two or more subjects, specifically focusing on science, technology, engineering, and mathematics within STEM education (Honey et al., 2014). However, integrating lessons is typically for the purpose of learner skill development and typically not on learner thoughts and feelings. Self-efficacy, how an individual judged their capability to learn and perform tasks, influences human functioning at the core (Schunk & Pajares, 2010). Motivation and perseverance to complete a task increases when students believe they can achieve the outcomes they prefer (Schunk & Pajares, 2010). Intentionally combining experiences designed to build self-efficacy in students with integrated STEM education could provide students with the skills and self-efficacy requisite of considering an occupation in science and technology. It has also been documented that women and certain racial ethnic groups (e.g., blacks, Hispanics, and American Indians or Alaska Natives) are underrepresented in science and engineering (Khan et al, 2020). However, women accounted for nearly half the workforce in life sciences, psychology, and social sciences (Khan et al., 2020). These occupations center around the actions, development, and study of living things. From the migration of orcas to human brain development, these occupations all impact the existence of organisms.

When young people are considering careers, literature suggests that careers which make a difference in the lives of human or animals are interesting to a broader group of people including women and minorities (National Academy of Engineering, 2008). Prior research has explored how the contextual framing of STEM learning, particularly life-centered or socially relevant problems, can influence student engagement and identity formation, especially among historically underrepresented groups (Screpanti et al., 2018; Ayar, 2015). While such contexts are not universally motivating, they may provide meaningful entry points for students who do not initially identify with traditional portrayals of engineering or technology. In this study, a life-centered robotics unit was used to explore how contextual design might impact student self-efficacy across diverse populations. The intent was not to generalize about preferences but to examine whether this type of context offers more inclusive learning experiences that support a broad range of learners.

One way to implement life-centered, inclusive STEM learning is through engineering design, a process that mirrors professional practice and engages students in solving meaningful, real-world problems (ITEEA, 2020). Engineering design consists of a systematic method of identifying problems and creating solutions to solve the problem and serves as the core of engineering practices as the scientific method guides science research practices (Committee on Educator Capacity Building in K-12 Engineering Education, 2020). The problems addressed by engineering design can include global-scale issues such as alternative energy sources, access to clean water, or infrastructure challenges (Committee on Educator Capacity Building in K-12 Engineering Education, 2020). To solve these global-scale issues, current STEM professionals engage in long-term engineering design and through the process create solutions to meet societal needs. In the K12 environment, robotics units are a common approach of delivering STEM education. Robotics platforms are ubiquitous, and range from student created vehicles and literary characters, to animatronic devices that utilize robotics within different contexts (Honey et al., 2014; Jung & Won, 2018; Screpanti et al., 2018). The motivation behind this study is that we hypothesize a robotics unit with a life-centered context could integrate multiple subjects, provide instant feedback, and allow for a project based-learning model within the unit thereby increasing student self-efficacy (Eguchi & Uribe, 2017; Chalmers, 2018; Ching et al., 2019; Karahoca et al., 2011; Murphy, 2001; Screpanti et al., 2018). Offering these kinds of robotics units in engineering and technology classrooms could allow more students to experience robotics education and receive the benefits provided by the experience.

To explore how integrated STEM education within a life-centered context might impact student development, this study implemented an in-class robotics unit designed to promote both technical skill acquisition and self-efficacy. Specifically, the study examined whether participation in a thoughtfully scaffolded, affordable co-robotics curriculum could influence students' confidence in their engineering abilities especially among those from underrepresented populations. The unit incorporated engineering design, experimentation, and problem-solving, aligning with integrated STEM principles. This investigation aimed to examine both the effectiveness of the learning experience and its equity across student demographics. The following research question guided this study: Do integrated robotics learning activities set in a life sciences context affect student engineering self-efficacy and if so, to what extent and is it the same for all students?

Literature review

Workforce Demands

The U.S. Bureau of Labor Statistics projects STEM occupations to grow faster than non-STEM occupations from 2019-2029 (U.S. Bureau of Labor Statistics, 2020). In 2018, the U.S. Department of Education published a STEM education five-year strategic plan outlining the current state of STEM education, the goals for the future, and four pathways for the successful completion of those goals (National Science & Technology Council, 2018). One of the pathways, encouraging students where disciplines converge, indicates a need to apply knowledge across disciplinary boundaries, both within and beyond traditional STEM fields, and promotes transdisciplinary learning as a significant objective under this pathway (National Science & Technology Council, 2018). Transdisciplinary integration of STEM fields in education allows learners to experience authentic challenges on a local or global platform and develop multiple critical thinking, analysis, and initiative skills when learners have early exposure to these challenges (National Science & Technology Council, 2018). In other words, the U.S. Department of Education believes successful implementation of this plan will provide Americans access to high-quality STEM education and assist the U.S. in becoming a global leader in STEM literacy, innovation, and employment (National Science & Technology Council, 2018). A high-quality STEM education includes transdisciplinary integration of STEM teaching and learning within STEM fields and other fields including humanities and arts (National Science & Technology Council, 2018). Integration of teaching and learning within fields provides learners with authentic challenges from local to a global scale (National Science & Technology Council, 2018).

Robotics as a Platform for Integrated STEM

Competitive robotics programs are large in scale and impact a large number of students. In 2018, researchers found that females participating in robotics competitions were 10% more likely to have interest in an engineering career than non-participants, and the longer students participated the more likely they were to enter a STEM field (Miller et al., 2018). Another study measuring the impact of FIRST Robotics, a national competitive robotics program, on attitudes and interest in STEM found that female participants were three times more likely to be interested in a career in science and engineering than non-participating females (Burack et al., 2019). Competitive robotics such as FIRST and VEX encourage students to build science, technology, and engineering skills in addition to communication and leadership skills (Burack et al., 2019; Stewardson et al., 2019). Robotics competitive teams require large budgets to purchase robotics materials, pay entry fees for tournaments, and cover travel cost to the tournament (Burack et al., 2019; Stewardson et al., 2019). In addition, robotics competitions take place outside of the classroom, and not all students are able to take advantage of the benefits of robotics competitions. These requirements make it difficult for all schools to offer a competitive robotics program. These limitations highlight the need for inclusive, in-class alternatives that can offer similar benefits to all students regardless of school resources or after-school availability.

One promising approach lies in integrated STEM education, which, like transdisciplinary learning, encompasses a variety of experiences within science, technology, engineering, and mathematics, possessing some degree of connection between two or more subjects (Honey et al., 2014). Researchers conducting a review of integrated STEM education defined five critical principles for integration (Üçgül & Altıok, 2021; Thibaut et al., 2018). The five principles described in Table 1 offer a useful framework for designing in-class robotics activities that connect content areas meaningfully and promote deep engagement.

Table 1
*Integrated STEM Education Principles**

Principles	Description
Integration	Combines content from science, technology, engineering, and mathematics
Problem-centered learning	Focuses on using real-world problems to create the context for concept application
Inquiry-based learning	Questioning, discussing, interpreting, using, and attempting to understand the content
Design-based learning	Using engineering or technological design
Cooperative learning	Centers around teamwork and collaboration with others in small group

*key principles for integrated STEM education, Üçgül & Altıok, 2021; Thibaut et al., 2018

Educational robotics platforms align well with this framework, serving as tools that bridge STEM disciplines through minds-on/hands-on application and inquiry. In a systematic literature review, Jung and Won (2018) defined educational robotics as a teaching tool, which for STEM subjects involves adapting robotics learning activities within existing lessons and curricula and requiring careful identification of course topics and objectives that instructors can integrate with robotics (Jung & Won, 2018). Robotics learning activities provided students with the opportunity to explore, create, and apply STEM knowledge anchored within a meaningful context (Ching et al., 2019). A 2011 study (Kim, et al.) outlined the use of Lego Mindstorms NXT robots to teach students guidance, navigation, and control, while another study conducted in 2018 (Chalmers) used WeDo 2.0 robotics kits in 2018 to teach computational thinking (Kim et al., 2011; Chalmers, 2018). Although the objectives were different, both studies required students to apply diverse knowledge from the four STEM subject areas while accomplishing the goals of the robotics learning activities. In 2017 Eguchi and Uribe used robotics in a science classroom to link science with engineering design, mathematics, and English Language Arts standards. In all of these studies students were required to work collaboratively in completing small formative tasks and mini challenges to build knowledge and skills which were then applied to a final culminating solution at the end of the intervention). These studies also provided examples of how robotics successfully integrated at least two or more STEM subjects within one platform while students worked collaboratively in a problem-based or inquiry-based environment supported by the five principles of integrated STEM education.

A systematic review of studies in educational robotics found that robotics learning activities increased student interest and motivation to study STEM (Anwar et al., 2019). Using robots provided students with opportunities to stop, question, and think deeply about technology while receiving instant feedback from the robotics system as they worked to complete a challenge (Eguchi & Uribe, 2017). The instant feedback provided to the learner from the robotics system engaged students in troubleshooting until the system functioned properly which allowed the learners to gain mastery over those skills (Eguchi & Uribe, 2017). Mastery events, completed by the participants, fostered increasing intrinsic motivation which helped to build competency in students (Driscoll, 2014). The project based-learning model used in many robotics research studies allows students to design solutions to authentic design challenges based on problems currently seen in society (Chalmers, 2018; Ching et al., 2019; Karahoca et al., 2011; Murphy, 2001; Screpanti et al., 2018). This method of delivery provided students with agency in the classroom and, based on the theory of self-efficacy beliefs, such provision of agency should increase the students' self-efficacy (Schunk & Pajares, 2010).

Self-efficacy

Targeting skill development to build up self-efficacy within STEM subjects can increase students' likelihood of entering STEM careers based on the theory of self-efficacy beliefs (Driscoll, 2014). Self-efficacy beliefs reflect how individuals perceive their capabilities, and is the foundation for inspiration and personal accomplishment (Schunk & Pajares, 2010). Not to be confused with self-esteem or self-concept, self-efficacy has little to do with how people feel about themselves and more to do with what people believe they are capable of doing (Schunk & Pajares, 2010). For instance, a student may have several academic accomplishments due to high self-efficacy levels and low self-esteem due to bullying from peers. Positive self-efficacy enhances achievement because individuals pursue activities when they feel competent and confident. In addition to determining the effort and perseverance an individual willingly puts into an activity, positive self-efficacy increases resilience (Schunk & Pajares, 2010). STEM careers require extensive education completed over multiple years of study. Based on prior research, students possessing strong STEM self-efficacy are more likely to put forth more effort and persevere longer in career preparatory programs than students lacking positive self-efficacy. Such research findings thereby associate positive self-efficacy with a more likely chance to succeed in a STEM career. Students build self-efficacy mainly through participating in experiences where they can successfully apply their knowledge and skills (Driscoll, 2014).

Participation in robotics activities such as camps, competitions, or classroom settings has been shown to strengthen students' self-efficacy. For example, involvement in VEX robotics was positively associated with increased confidence in mechanical, design, and programming skills (Stewardson et al., 2019). Students in robotics camps reported greater enthusiasm and self-confidence toward STEM subjects, often referencing the hands-on, challenging, and enjoyable nature of the experience as key motivators (Ayar, 2015; Knop et al., 2017). Similarly, classroom-based robotics activities led to significant gains in students' interest and perceived ability in engineering and programming, as well as increased aspirations toward STEM careers (Chang & Chen, 2020). These findings support the idea that meaningful, interactive robotics experiences can serve as powerful tools for enhancing student self-efficacy.

Method

Context

The research being reported is of the pilot study preceding the larger one funded by the National Science Foundation designed to investigate assistive robotics for formal learning environments based on prior work in informal learning environments (Knop et al., 2017). This pilot study was conducted in a suburban middle school and implemented in a seventh-grade engineering and technology classroom. The classroom teacher was a state certified teacher with a specialist level of education and more than 15 years of teaching experience. Thirty students ranging from 12 to 13 years of age were placed in the class by the school registrar, inclusive of those with learner accommodations and gifted. No prior experience with engineering and technology was required for students to enroll in and complete the engineering and technology course.

Research Design

A quasi-experimental approach was utilized in this study with data collection occurring after participants completed all the integrated robotics learning activities (Creswell, 2011; Gay et al., 2012). The quantitative method followed a one-group pretest-posttest, quasi experimental design with a retrospective pretest. The foundation for this design is rooted in previous robotics studies in educational settings that have implemented a pretest-posttest design with no comparison group (Chang & Chen, 2020; Knop et al., 2017; Üçgül & Altıok, 2021) and designs that include a posttest only to measure self-efficacy (Burack et al., 2019; Miller et al., 2018; Stewardson et al., 2019; Sullivan & Bers, 2019).

A retrospective pretest-posttest design was employed to evaluate changes in students' engineering self-efficacy following engagement in the integrated robotics unit. This method was chosen intentionally to reduce response-shift bias, which is a phenomenon whereby participants may overestimate (or underestimate) their initial ability due to a limited understanding of the concept being measured (Howard & Dailey, 1979). Response-shift bias is especially relevant to activities which introduce new or complex skills and where students need only gain a basic level of understanding in order to accurately assess their prior abilities following completion of the learning experience (Howard & Dailey, 1979). Self-efficacy, being a perception of an individual's capabilities within a specific context, is particularly susceptible to such bias in this novel approach to robotics. Retrospective assessment allows students to reflect more accurately on their starting ability using a frame of reference established during the learning activities. This approach is supported in STEM education literature as a more appropriate strategy when assessing shifts in student confidence or attitudes in experimental or project-based contexts (Bhanji et al., 2012; Lam & Bengo, 2003).

A pretest/posttest survey design was used as it gave the researcher the opportunity to measure participants' attitudes toward their ability and confidence within engineering (Creswell, 2011). Survey response items were chosen from the Engineering Skills Self-Efficacy Evaluation (ESSE) instrument (Mamaril et al.) The retrospective pretest and posttest surveys were administered together on the final day of the unit through Qualtrics. Students were instructed to complete two sets of self-ratings: one reflecting on their current level of self-efficacy, and one based on how they perceived their ability before the unit began. To support validity, the teacher clarified that there were no right or wrong answers and emphasized the importance of honest reflection. The retrospective pretest and posttest survey results presented a numerical description of the participants' engineering self-efficacy which was measured for differences between the posttest and retrospective pretest responses.

Treatment

Students participated in a robotics unit with the goal of creating an assistive co-robotic device used to help with human motion. Their device utilized electrical signals from the brain and an accelerometer to control servo motors on a robotic arm. An electromyography or EMG sensor attached to a student's arm muscle read the electrical output and filtered the information to be used in a student-created program for controlling a servo motor. The position within space, calculated and measured by the accelerometer, controlled a separate servo.

The robotics unit included approximately 2 weeks of activities taught by an Engineering and Technology teacher daily for 45 minutes each session. The participants completed the activities with a peer creating a cooperative learning environment (Thibaut et al., 2018; Üçgül & Altıok, 2021). The activities followed a 6E Learning by DeSIGN Model (Burke, 2014) lesson plan, an adapted version of the Biological Sciences Curriculum Study (BSCS) 5E Instructional Model (BSCS, n.d.; Bybee et al., 1987). As used in the curriculum developed by the International Technology and Engineering Educators Association (ITEEA), the adapted version is known as Engineering by Design (EbD) and requires students to engage, explore, explain, e*NGINEER*, enrich, and evaluate (Burke, 2014). The 6E Learning by DeSIGN Model supports a student-centered environment that blends context and concepts with inquiry.

During the first half of the unit, students engaged in experimentation with the core subsystems of the robot to build foundational knowledge for the culminating design challenge. The sequence began with a basic programming activity designed to link coding commands with physical responses, providing students with opportunities to observe and modify outputs based on input changes, an introduction to the concept of debugging. The unit then progressed to motor control, where students programmed a motor to rotate attachments to 0°, 90°, and 180°. When initial results were inaccurate, students adjusted the setup and reprogrammed until proper calibration was achieved. Building on this, students extended the task by attaching larger components to simulate shoulder and forearm movement, reinforcing the relationship between program logic and mechanical behavior. Once this foundational knowledge was established, the accelerometer and electromyography (EMG) sensor were introduced. Prior to their use, theoretical principles governing each sensor were discussed, after which students collected and analyzed data using graphs to explore how these signals could drive robotic movement (Figure 1). Each phase of the unit aligned with key tenets of self-efficacy development: scaffolding conceptual understanding, applying that understanding in practice, and ultimately engaging in mastery experiences to reinforce confidence and competence.

The second half of the unit engaged students in building the robotic arm prototype. The building process was scaffolded and organized for students and allowed modifications to meet the needs of the students or classroom constraints. Experimentation for comprehension activities required the students to utilize skills from mathematics, science, technology, programming, and engineering. Upon completion of the experimentation activities, students were challenged to apply the gained knowledge and skills to design and build the system (Figure 1). In addition to assistance from the teacher, participants were provided with tutorials to assist with the required tasks within each activity. The tutorials included a combination of video and written directions which progressed from step-by-step, specific directions to requiring the students to remember how to complete tasks to reinforce skill mastery. The teacher also delivered formative assessments to gage student comprehension.

Figure 1

Student Engagement in Robotics Programming

Sampling Method

This study implemented purposive sampling to select secondary schools with a diverse population. Purposeful sampling is appropriate when researchers believe the sample represents the target population (Gay et al., 2012). The suburban middle school selected included a mixture of students with different abilities and backgrounds, reflecting a diverse population (National Center for Educational Statistics, 2021). The middle school contained various socioeconomic backgrounds, family makeups, and ethnicities (National Center for Educational Statistics, 2021). The 30 participants from the selected school were enrolled in an Engineering and Technology class.

Ethical Considerations

This study was reviewed and approved by the Purdue University Institutional Review Board (IRB-2021-1073). Participation was voluntary and required parent consent and student assent before participation and/or data were collected. Students and parents were informed of their right to withdraw from the study at any time without penalty. All data were anonymized before analysis to ensure participant confidentially.

Instrumentation

Engineering Skills Self-Efficacy Instrument

Participants completed a retrospective pretest and posttest survey created using items drawn from the Engineering Skills Self-Efficacy (ESSE) Instrument. The original ESSE instrument was developed to measure the self-efficacy of undergraduate engineering students (Mamaril et al., 2016) and later validated to measure the self-efficacy of secondary school students (Jackson, 2018). The validation process included extensive analysis using both exploratory and confirmatory factor analysis to ensure the items measured the correct concept (Mamaril et al., 2016; Jackson, 2018). The retrospective pretest and posttest were tested for reliability in the Jackson 2018 study showing that item loadings were all significant (greater than 0.69) with significant correlational to engineering skills ranging from 0.69 - 0.80. Secondary education includes middle or junior high grades, ranging from 6 to 9, and high school grades ranging from 9 to 12, which includes the target audience for this study. The ESSE measured engineering skills self-efficacy on four constructs using a 6-Point Likert-scale for item responses (Jackson, 2018; Mamaril et al., 2016). Table 2 displays the constructs and questions used to build the participant scores on the ESSE.

Table 2
Engineering Skills Self-Efficacy Instrument: Constructs Measured

Construct	Questions on the Instrument
General Self-Efficacy	• I can master the content in the engineering-related courses I am taking this semester. • I can master the content in even the most challenging engineering course. • I can do a good job on almost all of my engineering coursework. • I can learn the content taught in my engineering-related courses. • I can earn a good grade in my engineering-related courses.
Experimental Self-Efficacy	• I can perform experiments independently. • I can analyze data resulting from experiments. • I can orally communicate results of experiments. • I can communicate results of experiments in written form.
Design Self-Efficacy	• I can identify a design need. • I can develop a design solution. • I can evaluate a design. • I can recognize changes needed for a design solution to work.
Tinkering Self-Efficacy	• I can work with machines. • I can build machines. • I can assemble things. • I can disassemble things.

Engineering Skills Self-Efficacy Instrument (Jackson, 2018; Mamaril et al., 2016).

Data Collection & Analysis

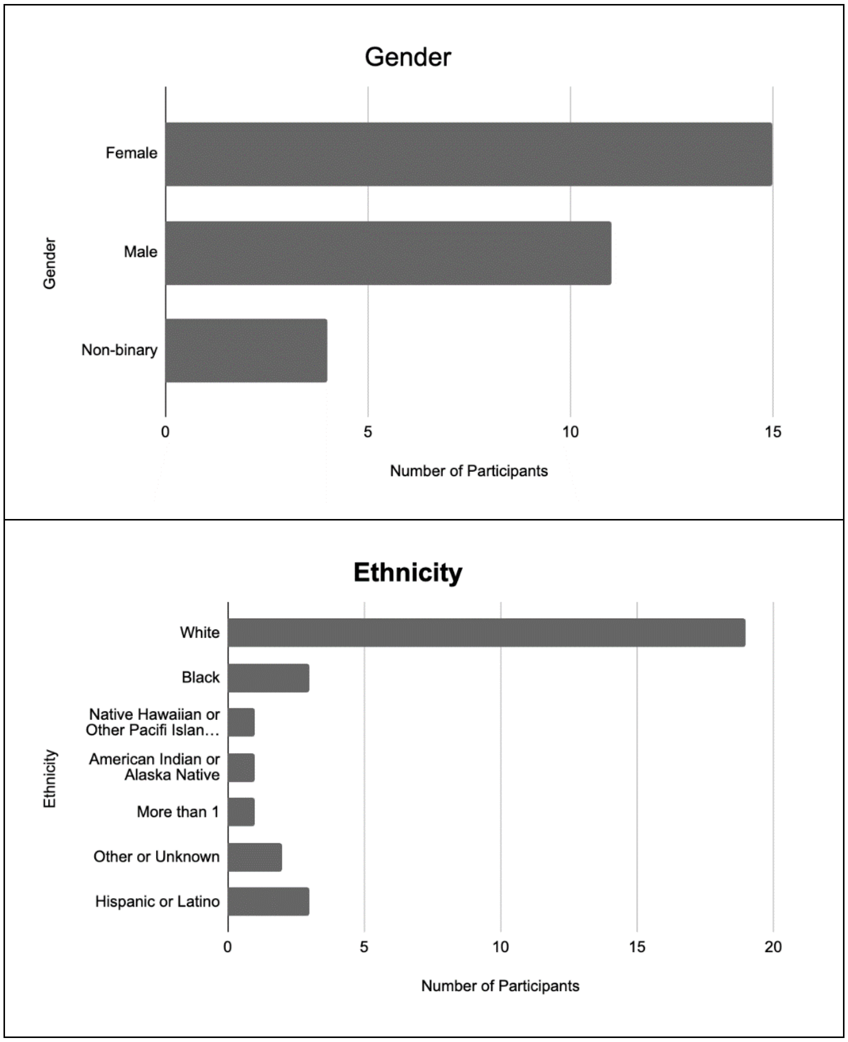
Data collection took place at the end of the robotics unit. On the last day of the unit activities, participants completed a retrospective pretest followed immediately with a posttest, both of which were created using items from the Engineering Skills Self-Efficacy (ESSE) Instrument. The students responded to items on the instrument according to how the robotics unit assisted them in building skill and engineering self-efficacy. The retrospective pretest and posttest administered online through Qualtrics included items to collect demographic information in addition to the ESSE survey using a 6-Point Likert-scale for item responses. Averages for 5 questions determined general engineering self-efficacy, 4 questions measured experimental self-efficacy, 4 questions measured tinkering self-efficacy, and 5 questions measured design self-efficacy (Mamaril, et al., 2016; Jackson, 2018). The scores from the retrospective pretest were subtracted from the posttest scores to determine the growth score for each participant. Once the scores were calculated, an exploratory, descriptive analysis was conducted using SPSS software to determine the mean, the distribution curve, standard deviation, outliers, skewness, and kurtosis of the growth scores. A normality test was conducted to determine which statistical tests were appropriate (Privitera, 2018). The researcher conducted a one-sample *t*-test to test for the significance of change with the entire sample. In addition, gain scores were tested with a Kruskal-Wallis Test for significant differences among subsets of male and nonmale as well as white and nonwhite participants after normality testing concluded in a nonnormal distribution. The nonmale grouping included female and nonbinary participants. The nonwhite grouping included students of Black, Native Hawaiian or Pacific Islander, American Indian or Alaska Native, Hispanic or Latino descent as well as participants with more than one race or unknown race. Incomplete survey responses were removed from the study sample.

Results

Demographics of 30 participants are represented in Figure 2 in terms of self-reported gender and ethnicity. Approximately one-third of the students were male, half were female, with only a very few reporting being non-binary. The majority of students were White, with a much smaller but relatively equal number of Black or African American and Hispanic or Latino students. The remaining population reflected equally low numbers of students reported identifying as Asian, More than on race, Other/unknown, Native Hawaiian or Pacific Islander, and American Indiana or Alaska Native.

Figure 2

Participant Demographics: Gender and Ethnicity



Retrospective pretest and posttest mean and standard deviation for each construct are shown in Table 3. The ESSE used a 6-Point Likert response scale where 1 meant the student was completely uncertain and 6 meant that they were completely certain of their self-efficacies. Results from the pretest assessment where students were to retrospectively consider their self-efficacy prior to engagement, mean scores for each construct were lower than the midpoint of 4.5

indicating they tended to feel as though they were somewhat uncertain, with Design self-efficacy at 2.45 being the least certain. On the posttest assessment where students were to consider their self-efficacy level following the intervention, across all four constructs each mean was higher. As presented in Table 3, Experimental Self-Efficacy revealed the greatest gain. Gains for the Design Self-Efficacy construct were the lowest, and still a full point below the neutral point indicating that while students made gains, they maintained feelings of uncertainty toward their design abilities.

Table 3

Engineering Self-Efficacy Evaluation Mean Scores

Engineering Self-Efficacy Constructs	**Pre (SD)**	**Post (SD)**	**Gain**
General Self-Efficacy	3.45 (1.27)	4.24 (1.01)	0.79
Experimental Self-Efficacy	3.88 (1.54)	5.32 (1.71)	1.44
Design Self-Efficacy	2.45 (1.16)	3.36 (0.99)	0.91
Tinkering Self-Efficacy	3.79 (1.35)	4.54 (1.23)	0.75

Note. n = 30; *p < .05, two-tailed, paired; †Effect Size (Cohen's d)

As presented in Table 4, the mean gain for General Self-Efficacy (M=.79) was more than three quarters of a point with similar results occurring in the mean gain score for Tinkering Self-Efficacy (M=.75) and both with standard deviations greater than 1 for each construct. Experimental Self-Efficacy revealed the greatest mean gain (M=1.08), followed by Design Self-Efficacy (M=1.13). Given the small population size for this study, Cohen's d was calculated to verify the practical strength attributed to the mean differences. In all instances, mean differences were substantiated by large effect sizes (1.22 to 1.72).

Table 4

Pretest/Posttest Data Analysis Results

Engineering Self-Efficacy Constructs	**Self-Efficacy Gain Score**				
	M	***SD***	***t***	***p***	†ES
General	0.79	1.33	3.26	0.003*	1.33
Experimental	1.08	1.21	4.90	≤ 0.001*	1.22
Design	1.13	1.53	4.04	≤ 0.001*	1.53
Tinkering	0.75	1.72	2.39	0.024*	1.72

Note. n = 30; *p < .05, two-tailed, paired; †Effect Size (Cohen's d)

The one-sample *t*-test analyzed the gain scores by comparing them to the test value of zero as zero represents no change in the participants. The *t*-test also included a two-tailed analysis to display positive or negative changes. The level of significance for this hypothesis test used the typical 5% where 95% of the gain scores fall within two standard deviations from the mean or $\alpha = 0.05$ (Privitera, 2018). The study gathered 30 complete responses from participants to the ESSE survey instrument including 11 males and 19 nonmales as well as 19 whites and 11 nonwhites. Students who did not complete both the retrospective pretest and the posttest were not included in the study data set due to incomplete data. Results from the one-sample *t*-test analysis performed in SPSS software are shown in Table 4. Results indicated significance ($p < .05$) for differences in pretest/posttest gains across all four engineering self-efficacy constructs.

A Kruskal-Wallis test analyzed the differences in gain scores between male and nonmale students as well as white and nonwhite participants. The results of the Kruskal-Wallis analysis are shown in Table 5 for male and nonmale participants and in Table 6 for white and nonwhite participants. Nonmales were slightly higher in each self-efficacy construct than males although differences were insignificant. White students had slightly greater gains in general and design self-efficacy while nonwhite students had slightly higher gains in experimental and tinkering self-efficacy. These gains were neither practically nor statistically significant. While not significant, we note that non-males started lower in both design and tinkering self-efficacy and ended higher which may be practically interesting. The analysis indicated a nonsignificant difference in gain scores for male and nonmale participants. Table 5 displayed the different in the preliminary and subsequent mean ranks for male and nonmale participants within the general, design, and tinkering self-efficacy constructs.

Table 5

Kruskal-Wallis analysis for male and nonmale participants

Engineering Self-Efficacy Constructs	Group	Pretest (SD)	Posttest (SD)	Self-Efficacy Gain Score		
				***M* Rank**	*H*	***p***
General	Male	3.89 (1.39)	4.18 (1.04)	12.09	2.68	0.101
	Nonmale	3.19 (1.15)	4.27 (1.02)	17.47		
Experimental	Male	4.06 (1.93)	5.48 (1.91)	15.32	0.008	0.930
	Nonmale	3.77 (1.30)	5.23 (1.64)	15.61		
Design	Male	2.73 (1.15)	3.26 (0.87)	13.36	1.08	0.299
	Nonmale	2.29 (1.16)	3.43 (1.07)	16.74		
Tinkering	Male	4.48 (0.97)	4.50 (1.10)	12.55	2.02	0.156
	Nonmale	3.39 (1.39)	4.57 (1.33)	17.21		

Table 6

Kruskal-Wallis analysis for white and nonwhite participants

Engineering Self-Efficacy Constructs	Group	Pretest (SD)	Posttest (SD)	Self-Efficacy Gain Score		
				***M* Rank**	*H*	***p***
General	Male	3.45 (1.02)	4.31 (0.97)	15.88	0.112	0.738
	Nonmale	3.44 (1.73)	4.10 (1.13)	14.75		
Experimental	Male	4.27 (1.14)	5.60 (1.43)	15.30	0.032	0.857
	Nonmale	3.10 (1.96)	4.77 (2.15)	15.90		
Design	Male	2.63 (1.05)	3.45 (0.83)	15.63	0.013	0.910
	Nonmale	2.10 (1.34)	3.18 (1.28)	15.25		
Tinkering	Male	3.83 (1.01)	4.81 (0.84)	16.95	1.68	0.195
	Nonmale	3.73 (1.91)	4.00 (1.70)	12.60		

Discussion

During the robotics unit where a life-centered context was front and center, participants engaged in an integrated STEM education experience in an effort to increase engineering self-efficacy. The research question guiding this study stated *"Do integrated robotics learning activities set in a life sciences context affect student engineering self-efficacy?"* In order to answer the research question, the study measured the effect of the robotics unit on student engineering self-efficacy. The Engineering Skills Self-Efficacy (ESSE) instrument was used to measure the engineering self-efficacy of participants within four constructs: general, experimental, design, and tinkering (Burghardt & Hacker, 2004; Crismond & Adams, 2012; Lomask et al., 2018). The robotics unit was implemented in a seventh-grade class offered in a suburban middle school. Middle school participants were those enrolled in a Engineering in Technology class assigned through random placement by the registrar.

A descriptive analysis of the survey data returned positive self-efficacy gains for the means of all four constructs with experimental and design self-efficacy displaying the largest positive gains. While experimental and design self-efficacy showed the largest mean gains and effect sizes, these results should be interpreted with caution. The large effect sizes across all constructs suggests a substantial impact on self-efficacy resulting from participation in the robotics intervention. However, these outcomes may also be reflective of the combined influence of the scaffolded, hands-on experimentation and the overall design task which reinforced skill development and confidence.

Strong self-efficacy levels help encourage learners to pursue activities they believe they can accomplish and are fortified to endure hardships to complete those activities (Driscoll, 2014). Students build self-efficacy mainly through participating in experiences where they can successfully apply their knowledge and skills (Driscoll, 2014). As participants worked through the robotics unit activities, self-efficacy levels increased indicating the participants became more confident in their ability to work through challenges and hardships that arose to complete an assigned task in their Engineering and Technology class. The Kruskal-Wallis Test indicated no significant difference between genders and no significant difference between ethnicities on all four constructs of the ESSE evaluation. The robotics unit affected student engineering self-efficacy positively and increased all four self-efficacy concepts within all students regardless of gender or race. This alignment between the unit's instructional goals and the constructs measured by the ESSE instrument reinforces the idea that well-designed, contextualized learning experiences can effectively promote specific dimensions of confidence in STEM. The findings support the notion that intentional integration of design experimentation and reflection can build both skill and self-belief which are the key drivers of long-term engagement in

STEM disciplines. The following offers further discussion of the four constructs addressed by the ESSE instrument and the interpretation of the results.

General Self-Efficacy

Participants answered five questions to measure general self-efficacy. The questions can be reviewed in table 3. A one-sample *t*-test indicated the gain was significant, coupled with a large effect. The large effect size indicates the robotics unit had a practically meaningful impact on increasing general engineering and technology self-efficacy.

The increase in general self-efficacy marked an improvement in the participants' feelings of achievement during the unit in general without reference to specific concepts of the course. General self-efficacy provides students with a foundational sense of confidence as they encounter new challenges. When students feel capable, they are more likely to engage in unfamiliar tasks and persist in problem-solving. Throughout the robotics unit, specifically during the research task, participants received instant feedback from the robotic system. For example, participants were required to position servo motors at 0°, 90°, and 180° before added the shoulder and forearm connections. If the attachments did not turn to the respective degrees, participants made adjustments to the attachment until the connect placement was reached. The confirmation of completing a task and receiving feedback to confirm successful completion marked participant mastery events resulting in an increase of self-efficacy. The increase in general self-efficacy observed in this study suggests that students developed a broader belief in their ability to succeed in engineering and technology contexts, even when faced with uncertainty or difficulty.

Tinkering Self-Efficacy

The tinkering self-efficacy construct included four questions for participants to answer. The questions can be reviewed in table 3. A one-sample *t*-test indicated significance between the pretest/posttest gains, together with a large effect size. The large effect size suggests that the robotics unit demonstrated the ability to positively increase confidence in tinkering while designing and creating a solution.

The increase in tinkering self-efficacy provides participants with more confidence while working with machinery and attempting to implement new ideas while creating solutions. As students create more real-world solutions, they will need to work with machinery that increases in complexity and danger. Students completing the robotics unit show an increase in working with machinery as they were required to utilize different machines to create the EMG controlled robotic arm. During the robotics unit, the students programmed motors, microcontrollers, and sensors to move parts. The program turned the servo motors to different degrees and the attachments had to be calibrated for the arm to move correctly. Before the students created the final design, discovery learning activities were included to provide the foundational skills the participants would need to calibrate the arm for movement. The experiments required students to tinker with and investigate the system. During the discovery learning activities, students built and disassembled the subsystems of the arm to test presented theories and learn the function of the subsystem within the whole robotics system. Presented theories included how accelerometers work, how the EMG sensor collects data, and how to map the data from the EMG sensor to the servo motor. Students participated in multiple activities that required assembly and disassembly of these different machines before combining the knowledge to build the final design, which supports increased tinkering skills.

Experimental Self-Efficacy

Participants answered four questions to measure general self-efficacy. The questions can be reviewed in table 3. A one-sample *t*-test indicated significance for pretest/posttest differences in gains, and which was substantiated by a large effect size. The large effect size suggests that as a result of participation in the robotics unit, the level of student experimental skill self-efficacy increased.

The robotics unit included three major experiments to understand the EMG sensor, servo motors, and the microcontroller. Each experiment required students to assemble different components; program the components' behaviors with the microcontroller and test the solution. After testing, participants reported on the results they observed and reflected on how each experiment would apply to the final. For example, during the EMG sensor activity students learned to connect the EMG within a circuit including the EMG sensor, a breadboard, the connection cord to the arm, and the microcontroller. The participants then programmed the microcontroller to output the electrical signals from the EMG on a graph. The graph was documented, labeled, and analyzed by the students through reflection questions. The students repeated a similar process to learn to use the servo motor. The robotics unit provides participants with multiple opportunities to successfully complete an experiment which assists students in analyzing solutions for success against criteria and constraints.

Design Self-Efficacy

The design self-efficacy construct included four questions for participants to answer. The questions can be reviewed in table 3. A one-sample *t*-test indicated significance for pretest/posttest differences in gains, and which was substantiated by a large effect size suggesting student participation in the robotics unit led to an increase in their level of design self-efficacy.

The robot affected student engineering self-efficacy positively and increased all four self-efficacy concepts within all students regardless of gender or race. The unit results indicated an equitable design challenge with the ability to increase engineering self-efficacy for everyone regardless of gender or ethnicity. Before students engaged in the engineering design process, the unit required participants to build knowledge of the subsystems through cooperative learning and experimentation. As students completed experiments with the subsystems, they acquired knowledge of how the system supported the overall robotic arm system and how each subsystem worked together. Specifically, students acquired knowledge surrounding how servo motors govern the movement of different attachments. This knowledge could then inform the design of the end-effector for the robotic arm while engaging in the engineering design process. The increase in design self-efficacy could reflect confidence in designing a system based on previous knowledge. The research step affords students the opportunity to find previous knowledge regarding the design challenge. Instead of depending solely on finding previous knowledge, students built their own knowledge in part through experimentation with the subsystems. The robotics system provided instant feedback to the students as a check to ensure students were correctly engaging with the subsystems.

Conclusion

Findings from this research are in alignment with established theories of self-efficacy, which emphasize the importance of mastery events, feedback, and contextual relevance in building confidence (Bandura, 1997; Schunk & Pajares, 2010). By incorporating experimentation and design challenges within a life-centered robotics curriculum, the unit provided students with repeated opportunities to experience success. Such conditions have been shown to be effective in strengthening engineering self-efficacy (Mamaril et al., 2016; Ayar, 2015). Moreover, the consistency in pretest/posttest gains across demographic groups suggests that integrated STEM experiences, when intentionally designed to be part of a life-centered robotics curriculum, can promote both equity and engagement. These experiences address calls in the literature for interventions that benefit underrepresented populations without disadvantaging others (Chang & Chen, 2020; Khan et al., 2020). This study contributes to the growing body of work showing that accessible, classroom-based STEM interventions can yield meaningful shifts in student belief systems, which are known to influence long-term academic and career trajectories. Future work could explore the application of this unit in other grade levels, school settings, or subject areas to examine how context influences outcomes. Additionally, a longitudinal study could assess the lasting impact of life-centered robotics experiences on student self-efficacy and STEM identity development over time. Expanding the study to include comparison groups or more diverse populations could further enhance the generalizability and depth of findings.

Recommendations

The strongest pretest/posttest self-efficacy gains reported in this study were observed in design and experimental self-efficacy, both of which were supported through scaffolded activities emphasizing subsystem experimentation and utilizing the engineering design processes. Based on these findings, future educators should be encouraged to integrate experimentation early in the design process to deepen student understanding and connect theoretical research to practical application. In addition, curriculum developers should also be encouraged to incorporate structured experimentation and reflective analysis into engineering lessons, providing students with hands-on opportunities to reinforce learning. The data also suggest that such integrated units can support equitable growth in self-efficacy across diverse student groups. As educators and curriculum developers work to integrate experimentation, over-arching educational systems must move beyond a one-size-fits-all approach. Designing equitable learning experiences which support diverse learners improves outcomes for all students and not just the historically underserved groups. Teachers and curriculum developers are encouraged to select design challenges that are socially relevant and accessible while still requiring application of rigorous STEM concepts.

Robotics curricula grounded in real-world, life-centered contexts can support broadening student engagement while addressing abstract STEM concepts. When students see how topics like electrical brain signals, muscle movement, and spatial reasoning related to their lives, they are more likely to persist through academic challenges and develop lasting confidence in their abilities. Contextualized experiences should be prioritized in future curricular development initiatives to ensure STEM learning remains relevant and inclusive.

Limitations

Significant efforts were made to ensure the validity of the study. However, as with most pilot studies, there are associated limitations. This study utilized a one-sample *t*-test for pretest/posttest analysis with no control group. The robotics unit also included a degree of novelty as this was the first-time participants utilized a robot based on human biology. The novelty of the unit may have positively influenced student enthusiasm and perceived self-efficacy gains. While this was the first time the classroom teacher delivered the robotics unit, the teacher was an experienced educator with training in robotics education.

Another important consideration is the close alignment between the unit's activities and the items on the Engineering Skills Self-Efficacy (ESSE) instrument. Many of the tasks such as conducting experiments or building machines mirror the specific items used to measure self-efficacy. While this supports the relevance of the instrument and alignment with instructional goals, it also introduces the possibility that increases in student Likert-scale responses may reflect short-term familiarity or recent success rather than broader, sustained growth in confidence. Future researchers could address this by including comparison groups, traditional posttest and pretest delivery models, or by using alternative instruments.

Statement on Artificial Intelligence

No AI tools were used in performing or communicating the work represented in this manuscript, except for Grammarly, which was used solely for grammar and punctuation checks. All aspects of data generation, analysis, manuscript development, and revision were conducted by the authors without AI assistance.

Competing Interests

The authors have no competing interests to declare.

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About the Authors

Tonya Isabell (tonya.isabell-bigz@basischina.com) is an International Computer Science, Mathematics, and Engineering Technology Teacher for Basis International School Guangzhou in Guangzhou, China. https://orcid.org/0009-0007-1236-8602

Nathan Mentzer (nmentzer@purdue.edu) is a Professor in the Purdue Polytechnic Institute at Purdue University. He is recognized as a Distinguished Technology Educator and National Teacher Effectiveness Coach, specializing in engineering and technology teacher education. https://orcid.org/0000-0001-9788-7901