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High school students' self-efficacy and emotional response to Makerspaces using the engineering design process

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Abstract

The educational Makerspace offers a potential transformation in today's high school in terms of physical and digital innovations. However, little is known about the efficacy of using Makerspaces intended for learning. This study explored the effectiveness of a high school Makerspace class focused on engineering design to enhance student learning and self-efficacy. Thirteen students designed emergency shelters for the homeless, guided by a framework emphasizing people, means, and activities. Data from interviews, photos, and observations were analyzed using a constant comparative method. Findings suggest that student motivation, accessible tools, and achievable tasks contribute to successful learning experiences in Makerspaces. Students' self-efficacy and emotional engagement varied based on instruction, perceptions, and materials. The study highlights implications for incorporating Makerspaces in science, technology, engineering, and mathematics education.

Keywords: Makerspace, high school, engineering design process, self-efficacy

INTRODUCTION

There has been growing interest in Makerspaces as more educators apply Maker activities in their classrooms. Many administrators have purchased tools and technologies and set up Makerspaces in their schools. However, there are few studies on the use of Makerspaces for learning. Hira et al. (2019) pointed out that, while educators incorporate Makerspaces into their curricular activities, each in their own way, "there is scant research investigating the efficacy of Making in these newly emerging Makerspaces for learning" (p. 1). Hira et al. (2019) said there was a need for a research-based framework to apply to the Makerspace environment so that students could develop self-efficacy. The conceptual framework they offered incorporates *people, means,* and *activities.* It addresses and meets the various needs of Makerspaces for learning.

In contemporary science education, educators play a leading role in ensuring that young students are prepared for the swift and profound changes in science, technology, engineering, and mathematics (STEM) that inevitably will occur during this era. The next generation science standards (NGSS), which guides STEM education, emphasizes technology and engineering education. One of the key ideas in NGSS is "engineering practices." This is different from "science practices." The former focuses on solving real-world problems, while the latter focuses on explaining and solving the problem through experimentation. The Makerspace concept incorporates both.

However, the integrated instructional approach of STEM teaching faces the challenge of incorporating new technologies and physical innovations in the curriculum. The Makerspace is one outstanding example of rising to the challenge. There are several different definitions of Makerspaces. Hira et al. (2019) said that "Makerspaces are environments where individuals use technologies to make physical artifacts within a community of fellow Makers" (p. 1). Other definitions have appeared on blogs and websites. One such is "A Makerspace is a collaborative workspace inside a school, library or separate public/private facility for making, learning, exploring and sharing that uses high tech to no tech tools" (https://www.Makerspaces.com). Sheridan et al. (2014) defined Makerspaces as "informal sites for creative production in art, science, and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and

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Contribution to the literature

- This study contributes to existing Makerspace research by providing qualitative, classroom-based evidence on how high school students' self-efficacy and emotions fluctuate throughout an engineering design task.
- It identifies four specific variables, teacher instructional strategies, student prior experiences, task materials, and peer interactions that shape self-efficacy development, offering a more nuanced framework than prior studies focused primarily on younger learners or broad Makerspace environments.
- The findings also differentiate high school students' emotional and self-efficacy trajectories from those of elementary students, suggesting developmental differences that the current literature has not yet addressed.

create new products" (p. 505). All agree that a Makerspace is an open area where students collaborate to craft, invent, make, and create a product, physically and virtually, to solve real-world problems. A Makerspace education enables students to integrate STEM knowledge and skills in solving real-world problems within and outside the school.

However, as Hira et al. (2019) pointed out, little is known about the efficacy of Makerspace lessons for learning. To fill that gap, this study aimed to uncover what variables that help high school students increase their self-efficacy about Making for learning. Specifically, the following question guided this research:

What variables impact students' self-efficacy about Makerspaces with an engineering design focus?

THEORETICAL FRAMEWORK

This study adopted the conceptual framework established by Hira and Hynes (2019), which employs Makerspaces for educational learning emphasizing the interplay among *people, means, and activities*. According to this framework, in a Makerspace environment: *People* provide, request, and dictate the means utilized. The *means* determine the range of possible activities within the space. These *activities* contribute to individuals' experiences, including their learning outcomes. Activities are shaped by the interests, goals, and experiences of the people involved, with all elements interconnected through a shared purpose. The required means are determined by the nature of the activities, while the means, in turn, influence the individuals' performance. For the Makerspace lesson designed in this study, the participants are students, the means include the space, tools, and machines, and the activity involves designing an emergency shelter for people left homeless by a natural disaster.

Makerspace Application in the American Classroom

In recent years, Makerspaces increasingly can be found in American schools (Dousay, 2017; Koole et al., 2017; McKay et al., 2016; Petrich et al., 2013). Makerspace is relevant to many subject areas, including fine arts, science, and engineering. It alters traditional classroom space as required by the nature of Making activities. Some of the key elements of Makerspace work are tinkering, playing, exploring, prototyping, creating, designing, making, testing, and failing, and retesting after revision (see **Table 1**) (Bevan et al., 2014; Holbert et al., 2017; Koole et al., 2017; Krummeck & Rouse, 2017; McKay et al., 2016).

A Makerspace in STEM education serves as a place where students can collaborate by imagining, crafting, designing, exploring, creating/inventing, making, and completing a three-dimensional object (Halverson et al., 2017; Holbert et al., 2017; Krummeck & Rouse, 2017; Peppler et al., 2013; Sheridan et al., 2014). By creating such a classroom, educators can maximize the meaningful learning of students by solving real-world problems using STEM disciplines (Bevan et al., 2014; Burke, 2014; Kafai & Peppler, 2011; Peppler et al., 2013; Peppler et al., 2016).

Many schools have been incorporating a Makerspace into the regular curriculum. Makerspaces may be located in a school classroom dedicated to Makerspace activities, or it can be used as an activity in a general classroom. Off-campus Makerspace locations also can be found in libraries, museums, and community centers (Sheridan et al., 2014).

The method of learning in Makerspace is hands-on, student-centered, project and problem-based (Brahms et al., 2014; Dousay, 2017; McKay et al., 2016; Peppler et al., 2013). Makerspace activities are more than the traditional techniques of cutting, bending, woodworking, and fabricating. It also uses contemporary technologies, such as 3D printing, robotics, soldering, circuitry, networking, coding, and programming, using all sorts of tools, materials, and digital applications during the process. The Makerspace educational environment is based on a creative culture and atmosphere where students collaborate, share, brainstorm, and engage in self-directed learning. While previous literature reports multiple attributes of Makerspace applications for learning, it can be summarized into four categories (see **Table 1**). In this present study, the goal of students' Making is to design an emergency shelter for people left homeless by a natural disaster. This project incorporates many

Table 1. Attributes of Makerspace for learning

Category	Example of keywords
Attributes of Makerspace work	Imagining, tinkering, playing, exploring, initiating, prototyping, creating, designing, taking risks, crafting, making, testing, and failure, retesting after revising, and completing a project
Methods of learning	Hands-on, student-centered, project-based, and problem-based learning
Activities of Makerspace	Making, cutting, bending, robotics, woodworking, soldering, circuitry, fabricating, networking, hacking, coding, and programming activity
Learning environments of Makerspace	Makerspace culture and atmosphere, community-oriented collaboration, sharing and brainstorming, and self-directing environment

elements of the four categories of Makerspace as shown in **Table 1**.

While educators use a variety of instructional delivery methods at the different grade levels, Makerspace is a popular addition to the school curriculum because it is student-centered, and it benefits the learning process in many ways. It uses hands-on activities to educate and engage young people and encourages them to stay on task. Also, it creates an environment in which students choose something that piques their interest and make an object out of their creative ideas. Yet, there seems to be no conceptual model that helps make a Makerspace class feasible to meet the diverse and practical needs at all levels of learning.

Makerspace in education is diverse and divergent. There is online Makerspace, museum-based Makerspace, Makerspaces in formal education, going from K-12 all the way up to graduate school (Litts, 2015; Peppler et al., 2016). In addition, in-service and pre-service teachers can use Makerspaces to design and make an object and to learn about how to incorporate the concept into a future classroom (Koole et al., 2017). A Makerspace is also being used in online teacher training classes with unique perspectives. An example was offered by Krummeck and Rouse (2017), who studied how college students tested the prototype of a boat they created and made using a 3D printer.

Many American universities are offering online graduate courses, and even degrees, that incorporate Makerspaces. Regarding online class with Makerspace, Oliver et al.'s (2017) study showed the final products of online graduate classes that provided a detailed instruction about the materials used and types of projects. When the instructor met the students in online settings, they worked together toward completing the project.

Unlike the online class, an in-person class offers a physical space and actual materials during class. Also, it allows for countless discussions and face-to-face collaborations when students are designing and making an object. However, there is no guarantee that a Maker project will be successful because it is a continuous process that only ends when the initial idea comes to fruition and produces a final complete product.

The recent pandemic has shown that we might not always have the luxury of in-person education. Although the Oliver et al. study was conducted in 2017 before COVID-19, it gives insights on computer-based instruction using Makerspace, to be used if online STEM becomes the new normal. The successful implementation of a Makerspace in online class suggests that we can go beyond traditional brick-and-mortar building STEM education.

Self-Efficacy and Makerspaces

Students' self-efficacy and motivation are correlated and intertwined (Bandura, 2001). As students become more self-efficacious about a specific task, they tend to become motivated to complete it. Bandura (1997) defined self-efficacy as "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" (p. 3). Using Bandura's (1997) concept of self-efficacy, several studies were conducted on the relationship between engineering design tasks and students' self-efficacy and emotions (Carberry et al., 2010; Goetz et al., 2006; Gumora et al., 2002; Pekrun, 2006; Vongkulluksn et al., 2018). The concept of self-efficacy explains how students feel confident about their ability to complete a specific task, as well as how excited they get to perform the task in class.

Vongkulluksn et al. (2018) investigated how students' (grade 3-grade 6) self-efficacy changed over the course of the semester and how self-efficacy and academic emotions are related to developing their interest in Makerspaces. According to the study, design-based Makerspace activities have the potential to develop students' interest. However, they found that the iterative design process can lead to "suboptimal outcomes" on students' self-efficacy and interest in a Makerspace class. Thus, they recommend that, as an instructional intervention, context-specific design-based Makerspaces be used by the instructor where students can show their fluctuating self-efficacy and emotional reactions to Makerspaces over the course of the semester. The study emphasized that the Makerspace intervention activity allows students to experience the real world of the design process.

Following this recommendation, student participants in the Makerspace research reported here experienced the reality of engineering design by creating an emergency shelter for people left homeless by a natural disaster. Self-efficacy refers to students' belief and confidence that they could complete the task and produce a finished and functional structure.

Bandura (1997) suggested four sources for increasing self-efficacy: enactive mastery (direct and successful) experience, vicarious (task similar) experience, verbal persuasion (encouragement and appraisal), and psychological and affective states (mood, enthusiasm, and anxiety). When the students successfully master a specific task or project, their self-efficacy increases and so does their feeling of success. In general, as people experience the successful completion of a specific task over time, their feeling and emotion may become deep-rooted with meaning, which is related to intrinsic motivation (Deci & Ryan, 1985). In an educational situation, Pekrun (2006) theorized that achievement emotions are related to two factors, the activity itself and task outcomes. Activity-related emotions are excitement, frustration, or disappointment, which students may experience at different stages of the project, whereas task outcome-related emotions are hope for successful completion or fear of failure. In this study, the focus is on mastery experience and the activity-related emotions that show how excited, frustrated, or bored students are as they attempt to design and build an emergency shelter for hurricane-related homeless people. When students are excited about engaging in an activity, it is called positive emotions; this will impact on their self-efficacy (Gumora et al., 2002; Goetz et al., 2006). Therefore, as Pekrun's theory (2006) explained, students' self-efficacy can be associated with activity-related emotions about the task. The activities on which this current study is based were designed to illustrate the educational and emotional outcomes of a high school Makerspace class for STEM learning.

METHOD

Research Design

This qualitative study explored the application of Makerspace in a high school setting. According to Patton (2014), a qualitative study, including field observations and interviews, typically focuses in depth on relatively small samples selected for a specific purpose. The researchers determined that an observational qualitative design was suitable because the goal of this study lies in the realm of new applications and new experiences and, thus, requires adequate contextualization (Merriam, 1998). The goals of this study were best accomplished through classroom observation due to the focus on the school-based application of Makerspace and students' self-efficacy.

Participants

A purposive sampling design was used to select participants for this study (Patton, 2014). Researchers selected one public high school in a midsize city in the Midwestern United States. Thirteen students at a high school (M = 10, F = 3) voluntarily participated in this study; all were enrolled in engineering class as an elective course. Groups of three to four students performed the Makerspace activity. A focus group was formed of three student volunteers (N = 3, aged 17-18). Interviews with those participants allowed researchers to investigate students' self-efficacy and achievement emotions related to the Makerspace class. This was a nonrandom convenience sample, as they were willing and available to participate in the study (Patton, 2014).

Intervention: Makerspace Lesson Designed for Learning in High School

One high school classroom (11th grade and 12th grade) was set up for a Makerspace class that met twice a week for six weeks. The instructor, who had taught high school engineering courses for five years, introduced an engineering challenge by discussing the natural disasters that often impact the region in which the students live. Tornados and floods could leave thousands of people homeless. So, the task was relevant to the students' lives.

The NGSS's three phases of engineering design were used to solve the challenge (NGSS Lead States, 2013).

1. **Phase I.** "Defining and delimiting engineering problems" involves stating the problem to be solved, as clearly as possible, in terms of criteria for success and constraints, or limits.
2. **Phase II.** "Designing solutions to engineering problems" begins with generating a number of different possible solutions, evaluating potential solutions to see which ones best meet the problem's criteria and constraints.
3. **Phase III.** "Optimizing the design solution" involves a process of tradeoffs, in which the final design is improved by trading off less important features for those that are more important (p. 2).

The teacher then provided the Maker class with the engineering challenges, constraints, and criteria as follows:

Engineering challenge:

(a) design a structure that could be quickly deployed as an emergency shelter after a natural disaster,

(b) create a 1/12 scale architectural model of the design, and

(c) perform an engineering structural analysis showing that the structure can withstand all necessary dead, live, weather, and seismic loads.

Constraints:

(a) be structured to allow two people to sit, stand, and sleep horizontally,

(b) provide four cubic feet per person of storage for personal belongings, and

(c) be built in such a way as to be completely sealed from the weather, with a floor raised above the ground by at least one foot.

Criteria:

(a) lightweight, to allow air transport,

(b) small, at least when packed, to allow many units to be stored and shipped in a truck or plane,

(c) durable and secure for at least 30 days,

(d) comfortable, and

(e) usable in all seasons in any place in the lower 48 states.

Students then went to work in groups of 3-4 to design and build their structure.

Data Collection

Data were collected using interviews, photographs of the Makerspace classroom, and observational field notes throughout the Makerspace activity, marking time points of the task (early, middle, end) to account for changes (low, high) in self-efficacy and emotions.

Interviews

The researcher interviewed three volunteer students (names Amelia, Kevin, and Mark are pseudonyms) to understand their experiences, self-efficacy perceptions, and interpretations of the Makerspace experience (Merriam, 1998). The focus group interviews were audio-taped and transcribed. The focus group interview protocol included questions centered around students' self-efficacy and achievement emotions of the Makerspace. Among the questions were as follows:

1. In general, how would you describe this Makerspace class?
2. What aspects of the Makerspace stand out as the most beneficial to you?
3. Would you share with me how excited or frustrated you are while designing an emergency shelter for a hurricane-related homeless household?

While observing what and how students made as part of their project, the researcher observed and interviewed the three volunteers whenever the opportunity became available, the students were asked about their understanding of how the engineering design process could be used to solve problems. Follow-up questions also were asked.

Photographs

The pictures of the Makerspace classroom were taken while the students were at work. Information about artifacts, classroom environment, and students' behaviors was recorded in field notes. Photocopies, photographs, and transcripts helped provide "thick descriptions" of data (Carspecken, 1996, p. 47).

Observational field notes

Observational field notes made up another source of data. The field notes depicted how students built their designs. Each picture of the student's activity had quick sketches and jottings of key words. In addition, the field notes helped to reconstruct conversations and emotions that the students had at the time of "critical events" (Bogdan et al., 2003). As Spradley (1980) suggested, the content of the field notes included physical settings of the classroom, students' behaviors, activities, and observer comment.

Data Analysis

Using a constant comparative method (Glaser et al., 1967), two researchers individually read and re-read interview transcripts until they identified a unit of data, which refers to "any meaningful (or potentially meaningful) segment of data" (Merriam, 1998, p. 179). All transcripts were de-identified by removing identifying information prior to analysis. The first coder is a graduate student in education, and the second is a professor of science education. Both had teaching experience in a Makerspace class. As they read interview transcripts, the two wrote down emerging themes and insights in terms of students' "self-efficacy" perceptions in relation to "achievement emotions," i.e., completing tasks, and questions in the margins. Then they carefully checked, revisited, and compared notes until they agreed on the students' self-efficacy perceptions and emotions presented in interviews. They then confirmed their understanding by adding similar evidence from field notes and photocopies according to time points. They also conducted a cross-case analysis of all three kinds of data (interviews, photocopies, and field notes) in order to refine, confirm, or refute the preliminary analyses (Yin, 2003). Finally, two coders highlighted themes and wrote coding numbers that aligned with the research question.

RESULTS

This study focused on the activity of a Makerspace lesson, rather than on the outcome, in order to investigate students' perceptions of self-efficacy and their task-related feelings. Through the engineering design process, participants created a shelter to house people left homeless by a natural disaster. **Table 2** shows how students proceeded during the process of engineering design over time. As shown in **Table 2**,

Table 2. The process of engineering design and the amount of time taken

Phase	Process	Week					
		1st	2nd	3rd	4th	5th	6th
I	• Identifying problems: Define problems/delimit constraints						
II	• Designing: Create and design different solutions • Prototype: Build and test multiple protypes • Feedback: Provide feedback						
III	• Optimizing: Make trade-offs • Improving: Select, test, and implement solution						

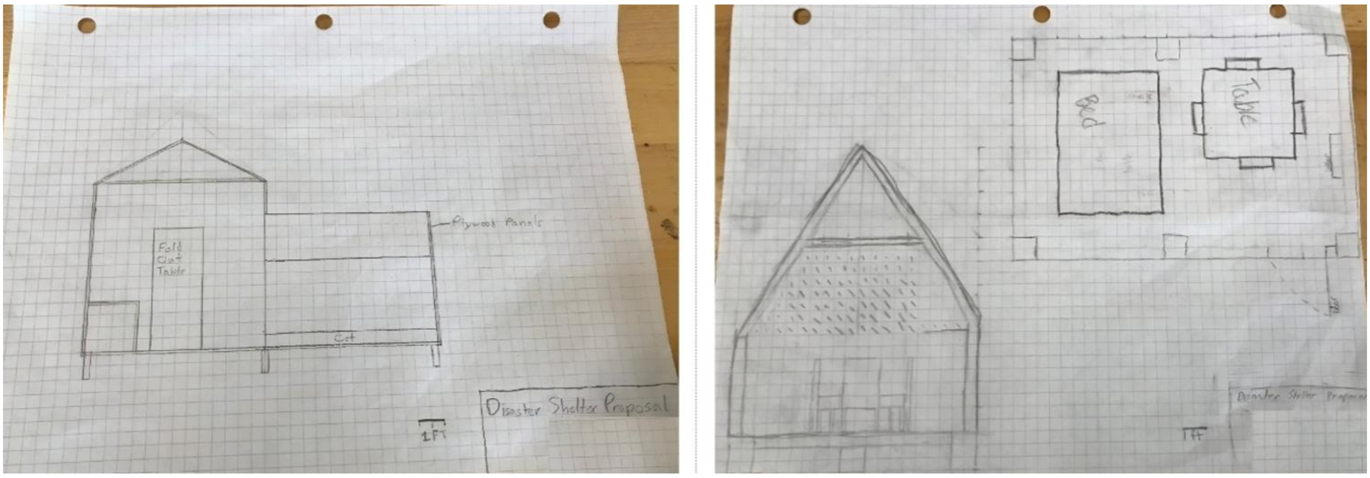

Figure 1. The drafts of students' design (Source: Field study, from the Makerspace Project)

students identified the problem within one week after the teacher discussed the context and the constraints (week 1). Designing and creating a few possible structures, as well as building and testing protypes, took the longest time (week 2-week 4), while the optimizing phase took two weeks (week 5-week 6) despite the different pace of each group.

In the introduction session in week 1, the teacher acknowledged that the students were not experts in any of the disciplines involved but should use what they know and learned to create their emergency structures. The teacher provided design constraints with a list of materials to give the students an idea of how to proceed and bring this project to completion. Then the teacher showed the students how build an "architectural white model," from cardstock, wood, foam core, and other easy-to-work materials. They built their models to a scale of 1/12th, where one foot in real life equals one inch on the model. Individually, the students came up with different shelter ideas and sketched them all on plotting paper. The students used a matrix, supplied by the teacher, evaluated all designs on each criterion, and selected one leading design.

Figure 1 shows an example of a high school group's Makerspace work on "structural design" in engineering. The teacher's role was to oversee each group's progress. Sometimes he asked questions and provided feedback, but generally remained silent, even if the group was off-track, so that the students could find their own solutions in phase I-phase III.

Figure 1 shows the design of an emergency shelter where one foot in real life equals one inch on the model. They put a legend of 1ft in the lower right corner in the plotting paper. Students indicated that the teacher's presentation of an architectural white model was very helpful as they imagined and planned their design. Amelia explained,

> When my teacher explained the constraints and challenges of our engineering design, to be honest with you, I was totally off the track because I've never experienced engineering design before; so, his languages blew my mind. But he then showed us an architectural white model to match what he was talking about. That was awesome! My mind got brighter 'cause it helped me understand what he was talking about so I could see details of what each [term] meant.

Figure 2 shows one white model completed in a high school Maker class where students were working with tools and machines to make. The "white model," then, helped scaffold what the project entailed and how it could be done. Amelia's frustration changed to excitement by virtue of teacher's architectural white model. As shown in this case, the teacher's instructional methods impacted his student's emotions in a Makerspace class.

Figure 3 shows one prototype that the students built in a high school Maker class using the engineering design process over the semester. They designed,

Figure 2. The white model completed in the Makerspace of an engineering class (Source: Field study, from the Makerspace Project)

Figure 3. The real shelter built by the students (Source: Field study, from the Makerspace Project)

brainstormed the potential solutions, created a prototype, and tested the solar panel and electric line and light bulbs, and built a real shelter.

The high school students in this study said they chose the Maker class because they love engineering and are determined to seek a career in STEM fields. Kevin said, "My dad is an engineer; so, I also would like to get a job in engineering field because I like making things by designing something that helps solve a problem in the real world. I believe engineering will open a whole new world for me in the future." Kevin seemed already motivated by his father's job, and his team designed an excellent emergency shelter with room for two people to sit, stand, and sleep horizontally, as well as four cubic feet per person of storage for personal belonging.

Kevin could see the benefit of being an engineer based on his background and family connections, which may have impacted on his motivation in a Makerspace class. Mark did not grow up in the same environment as Kevin, but agreed with his classmate:

> I agree with Kevin, and I think that engineering helps to make our city better by building safe homes, bridges, and towers, reconstructing a smart city, and even building an emergency shelter just like what we do in this class would need a lot of engineers. Like Kevin, I would like to pursue my career in STEM fields, but my biggest challenge is math because I am not confident about it. In math class, I struggle with it but I will try.

Mark believed that his math performance would prevent him from pursuing the career in STEM that he clearly wanted. Mark's motivation and emotions in the Makerspace class should have been impacted by his problems with math; his self-efficacy was low in mathematics, although he aspired to be an engineer. As revealed by the observation notes, however, Mark was actively engaged in collaborating and brainstorming. He took the initiative, led the discussions, and came up with more new ideas more than anyone else in his group. Mark expressed his positive feelings about Making:

> I love helping people, I mean I've done it many times and do. So, I got excited when we got to design a shelter that could be used for people devastated by hurricanes like Katrina. We live together in this world, and those who went through a hard time, they definitely need help from others. We got to help each other. My family's house was devastated by a tornado one time, we got a lot of help and assistance from

many organizations and people as a community. Maybe I got my attitude from there.

Mark seemed motivated and excited about the project. Mark's confidence and positive feeling seemed to stem from his past experience and personal orientation in life. One aspect of self-efficacy in Makerspaces can be inferred from this, especially in engineering. However, Mark's confidence, like that of his classmates, fluctuated as the project progressed; it was low in the beginning and gradually increased toward task completion. The interview below shows how the confidence and emotions of Kevin, Mark, and Amelia changed over time as they moved toward accomplishing the engineering task:

Kevin: Wait. No … hey guys we got to check the constraints and criteria. Come on …

Interviewer: What was the challenge in this Makerspace class?

Kevin: I don't know about others, but sometimes I tried once, that didn't work out, I revised it and tested it again, but it failed … it looked like our group project was in a chaos which was so disappointing and discouraging, and I almost came to a point of "give-up." For instance, we designed our temporary shelter to accommodate two people who could stand and sleep horizontally. But we mistakenly did not consider four cubic feet of storage per person when we cut the wood. It was actually four feet long in each length, so we ended up with a double size of storage per person. Phew. My team members encouraged each other and convinced us we could make it. So, we had to go back and recut it. When the project went as planned, I felt confident because the project was under control! In the end, I was so happy when our solution worked out nicely. I felt like I could do other similar projects all by myself.

Mark: I agree. We often made mistakes in the beginning, but we did not give up and, actually, we couldn't because we put too much time and effort into passing this course. I was disappointed and got little interested when we had to do it over again. But we double checked our design and started again.

Interviewer: Can you explain what you meant by 'We often made a mistake in the beginning?'

Mark: Oh, I meant that I miscalculated the scale when I cut the wood for the door on a Table Saw. Based on our group design, the length (3 ft) and width (1.5 ft) of the door should have been 1/12th of each side (Note: which is around .25 ft for length and .13 ft for width). But my friend calculated it and told me that mine was way bigger than what it was supposed to be. So, I had to cut it again accurately, and I was disappointed and felt bad emotionally because this project showed my poor math skills. I knew I was not good at mathematics, but it actually turned out bad, which was so discouraging me and lowered my confidence level as well. Personally, I was just not happy at that time. But as Kevin said, we felt good because we corrected it as a team and made it successfully.

Kevin and Mark were in the same group. Kevin forgot to consider constraints initially and went back again and corrected the problem. His self-efficacy was affected by the mistake. His emotion was negative, as he said he was "disappointed" and "discouraged" because he wasted wood and time. However, his team started over and successfully completed the project. Kevin regained his confidence in his ability to solve engineering problems and said that he felt he could do any other projects by himself

Mark was the outstanding case of the ups and downs of self-efficacy and emotion in engineering design. He made a mistake in calculating the scale of part of the project and created a door that did not meet the design constraint. So, he had to discard the original door and cut a new one to size. He demonstrated low self-efficacy when he realized he miscalculated the scale. His emotion was deeply negative because he felt his poor mathematical ability resulted in poor engineering design. However, he felt the positive emotion of achievement when he and his team corrected the mistake and made the door to the correct scale.

When asked about the materials they chose, Mark and Kevin said that they used wood. Although they had not worked with wood before, they said it looked sturdy and they felt comfortable with it. Amelia did not respond. So, the interviewer asked a question about her self-efficacy and emotion:

Interviewer: Amelia, can you share how you did your group project and how your confidence shifted?

Amelia: Sure, I know I was not confident at all in the beginning of the project because the scope and terminology are beyond my knowledge and experience when my teacher explained about the engineering design task. But my mind got brighter when my teacher explained again using a white model since it helped me a lot to grasp the scope and what each terminology meant clearly. When I talked about the house scale, I felt so happy because my ideas were accepted and used by our group members for the shelter.

Interviewer: Can you tell us more about your ideas that were accepted and used?

Amelia: Sure, I suggested that we make five legs underneath the house instead of four so that one more supporting leg make it studier underneath. The dimension of each leg is length (1 ft) x width (1 ft) x height (2 ft). The height is double the size because it is humid area so the floor should be distant from the ground.

Interviewer: Can you share with us a little more about how you felt about the shelter project?

Amelia: Like Kevin and Mark, my emotion and confidence were up and down throughout the project. In the beginning, I felt negative because I did not grasp what I was supposed to do due to lack of my understanding. During the project, I participated in the group work by offering my ideas. Sometimes it took us nowhere when we realized that two foam boards did not fit perfectly between wall and roof. Toward the end, I was so delighted to see my team complete the project successfully after we corrected it.

Interviewer: BTW, which material did your group choose and why?

Amelia: We chose foam boards because it was light and easy to cut and handle. It worked out pretty good for us. No one in our group had woodwork experience, so we were kind of scary using a Table Saw.

As shown in the interview, emotion and self-efficacy fluctuated during the evolution of the project. All the participants felt negative when they had little understanding, faced setbacks, or their project did not go as planned. They felt exuberant when they made the elements of the project successful and became self-efficacious when they confirmed that their solution worked as expected (Bandura, 1977).

DISCUSSION

To contribute to the understanding, identified by Hira et al. (2019), about how Makerspace is applied for learning, this study focused on variables that impact students' emotions and self-efficacy about Makerspaces with an engineering design focus.

Self-efficacy and emotion become critical in performing a specific task in Makerspaces. When students become highly confident in their abilities, their academic performance is likely high (Ashton et al., 1986; Bandura, 1997). Makerspaces have unlimited potential for nurturing self-efficacy of high school students through the solving of an engineering problem. As demonstrated in the results section, high school students' emotional reactions and self-efficacy fluctuated throughout the project. Given the complexity and iterative nature of the engineering design process (NGSS Lead States, 2013), students experienced some level of positive and negative emotions and a sense of self-efficacy throughout the design process depending on three variables: teaching strategies, student factor experience, and relevant material.

First, the teacher of the Makerspace class could influence students' emotions and self-efficacy by using appropriate instructional methods and techniques. In this case, the teacher used two distinctive strategies: a clearly defined task and the creation of cooperative groups. In Week 1, the teacher used a white model to deliver a clearly defined task because he expected that some students had never been involved in the process of engineering design. The teacher's explanation, using this student-relevant artifact at a critical time of student understanding, was effective especially for those who lacked engineering background knowledge and experience.

The instructor also created cooperative learning groups. Kevin and Mark were in the same group, while Amelia was in a different group. This instructional strategy worked effectively as Mark and Kevin managed to complete their project successfully although they struggled in the beginning of the design process. Bandura (1994) stated, "Cooperative learning structures, in which students work together and help one another also tend to promote more positive self-evaluations of capability and higher academic attainments than do individualistic or competitive ones" (p. 79). Pedagogies, such as cooperative learning and clear instruction using student-relevant methods, do foster students' self-efficacy. As such, the findings of this study supported the conclusion of Fencl et al. (2005) that teaching strategies can and do influence students' confidence in completing a task.

Second, students' abilities influenced their emotions and self-efficacy. Participants felt negative in the beginning of the design process when the project did not go as planned, but their emotion turned positive when they completed the project successfully by meeting the constraints and criteria. As such, the high school students showed positive emotional reactions to Makerspace activities when the project went smoothly as planned. Kevin, for example, convinced himself that he could gain high confidence by saying, "the project was under control." He felt he could do other similar projects "all by myself."

Failures and successes are an integral part of the engineering design process (NGSS Lead States, 2013; Park et al., 2018; Vongkulluksn et al., 2018). Throughout the project, students experienced the challenges and successes of that process and said that they better understood the attributes of working in a Makerspace, including perseverance, risk taking, building knowledge, and resilience so that they had the confidence improve their academic performance (Ashton et al., 1986; Bandura, 1997; Margolis et al., 2006).

However, Mark's case seemed to be unique, which offered a potential clue to what Vongkulluksn et al. (2018) meant when they questioned, "whether the declining self-efficacy and interest trajectories we found were typical of students participating in Makerspaces" (p. 17). Unlike the declining of elementary students' self-efficacy and interest in Makerspaces, high school students' change in self-efficacy is minimal. For example, even if Mark's self-efficacy was low when he felt challenged, or was frustrated, his attitude likely did not change. As shown in his interview, Mark learned that his lack of mathematics proficiency would work against him if he wanted to make a career in the engineering field. However, his attitude of "keep trying and willingness to try" kept him motivated and made a difference in his performance. Considering that Vongkulluksn et al.'s (2018) study was conducted with elementary students (see their claim above), their claim may have to be re-interpreted depending on the subjects. Mark was a high school student, and his self-control is discernable in comparison to elementary students' (Bergin et al., 2015, see Ch. 7). Students' self-control impacts their academic achievement (Ponitz et al.., 2009). The finding of this study suggests that students' self-efficacy and emotions are likely related to one's self-control in their ability. This aspect of a Makerspace class designed for learning is to be further studied. Therefore, this study suggests that there be a longitudinal study on how attitudes and self-control function in the relationship between self-efficacy and interest as students' progress through the grades.

Third, task material is another factor to consider when planning an engineering course. The research findings suggest that the activity materials must be designed to increase the self-efficacy and positive emotions of the learners. As shown, Kevin and Mark based their choice of wood on their past experience with the material to avoid potential challenges and kept their self-efficacy high. Amelia said her group chose a foam core board which they found it easy and familiar, rather than challenge their abilities by working with an untried table saw. Both groups, then, chose task materials based on their past experience and within their confidence level.

Fourth, all three students received positive feedback or encouragement from peers in their team when they encountered design challenges. This social feedback provided emotional support and practice strategies, enabling students to complete the design task. This finding confirms previous research (Cooper et al., 2020; Symeonides & Childs, 2015), which showed that social interactions allow students to alleviate negative responses or receive support. Amelia emphasized that having her ideas accepted by her peers was a critical moment because it potentially enhanced her emotions and self-efficacy in engineering. This aligns with the findings by Leaper et al. (2011), which reported that female students' interest in science and math courses was positively affected by peer support.

The findings of this study showed a tendency that students' self-efficacy and emotions were influenced by the teacher's instructional methods and strategies, student's ability, and task materials. In addition, the findings indicated that self-efficacy was related to emotions as the tasks progressed. Previous researchers also found a connection between self-efficacy and emotions in Makerspaces (Goetz et al. 2006; Vongkulluksn et al., 2018).

Regarding the fluctuation of high school students' emotions throughout the completion of the shelter task, students demonstrated various emotions based on their previous knowledge and experiences during the engineering design process. Amelia initially showed negative emotions (e.g., frustration, anxiety) because she lacked the knowledge to envision solutions to the design challenge. Previous studies also reported that students' prior knowledge is a crucial factor that predicts their emotional responses and performance in STEM education (Wang et al., 2022; Yang & Quadir, 2018). Conversely, Kevin and Mark demonstrated positive emotions (e.g., excitement and joy) when they first engaged in the task because they had intrinsic motivation and interest in engineering. Kevin showed his desire to become an engineer based on his family background, and Mark also displayed his motivation to help other people by using engineering. These students' initial responses to the design task echo a report by Jones et al. (2019), which found that first-year engineering students demonstrated moderate to high levels of positive emotions, including curiosity and interest, while negative emotions were also presented with low ranking at the beginning of the semester.

In the middle of the engineering design task, three students exhibited negative emotions such as confusion, frustration, or disappointment due to unexpected challenges. Since Kevin and Mark were in the same group, both students expressed that they were at the point of giving up because of a measurement issue. Kevin was frustrated because he felt that the project was out of his control, and this uncertainty caused him to feel negative emotions. Mark felt disappointed because he believed the challenge was caused by his lack of mathematical ability (i.e., math knowledge and skills). However, Kevin and Mark accepted their mistake and encouraged each other to overcome the challenge. Amelia also struggled as her team encountered a significant design problem. The students' struggles during the design process are inevitable because iteration and failure are inherent aspects of engineering (Park & Bae, 2020; Wynn & Eckert, 2017). Negative emotions arise when students feel uncertain about how to control a task or doubt their abilities to accomplish the desired results (Pekrun et al., 2007). Negative emotions can reduce interest and motivation (Vongkulluksn et al., 2018), but they could also enhance students' motivation to overcome challenges (Pekrun, 2017).

By the end of the design process, all students displayed positive emotions, such as enjoyment, happiness, and satisfaction, and felt confident in engineering tasks. Three students' emotional trends in the design process are in line with the findings of Jones et al. (2019), where increased negative emotions suppressed self-efficacy, but positive emotions significantly decreased during the design process. By the end of the semester, students exhibited positive emotions, which positively influenced their self-efficacy and final grades (Jones et al., 2019). The positive emotions observed at the end of this study were closely related to students' self-efficacy. This finding supports previous studies (Goetz et al., 2006; Pekrun et al., 2006), which explained that positive emotions are associated with high self-efficacy, whereas negative emotions negatively influence self-efficacy beliefs.

In summary, students in this study were new to engineering design tasks and had a low level of confidence at the beginning of the project of creating an emergency shelter. They attained higher levels of confidence in their ability to complete the task toward the end of the project. In other words, they grew in self-efficacy, although their confidence fluctuated with their success or failure at different stages of the process. Confronting new and challenging situations, that they found frustrating and disappointing at times, the cooperative groups of high school students in the Makerspace seemed to be working well on the designated task. Despite setbacks, and occasional disappointments positive emotions generally remained high, and they did not give up. They learned from their mistakes and took the slim chance of starting over by relying on their prior knowledge. The "willingness to try," either motivated by the class goal or personal ethos, likely created room for growth in adaptability and persistence and led the students to regain their self-confidence in completing the Makerspace task. As such, this finding empirically supports the relationship between self-efficacy and emotions in Makerspaces designed for learning (Bandura, 1977; Brígido et al., 2003; Williams, 2009).

CONCLUSION

Makerspace is in great demand for students to work on various projects in schools. A Maker class designed for learning requires the dedication of a space or a physical reorganization of a regular classroom so that students can work creatively and freely on hands-on projects. In this study, high school students worked in such a classroom to complete a Makerspace project specifically using the engineering design process. The goal of the study was to determine the variables that grow students' self-efficacy and emotions as they complete such a task. The results show the importance of four factors:

(a) teacher's instructional methods and strategies,

(b) student's ability and prior experience,

(c) task materials, and

(d) social feedback and teamwork.

In other words, Makerspaces have the potential to help increase students' self-efficacy and their positive emotions in the engineering design process and promote learning all the STEM concepts.

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