7-2021

The Impacts of Mastery Experiences, Vicarious Learning, and Role Models on Engineering Self-Efficacy in Middle School Students

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Submitted on July 15, 2021

in fulfillment of final requirements for the MAED degree

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Advisor: Megan Olivia Hall Date: July 15, 2021

Acknowledgments

I would like to express my gratitude towards the many outstanding professors at Saint Catherine University who developed relevant and meaningful courses. Thank you to all my family and friends who encouraged me throughout the research process. I am forever grateful to my parents for modeling determination, nurturing my love of science, and only being a phone call away. Thank you to our puppy, Goose, who took me on many walks through quarantine and graduate school when I needed it most. Finally, I have infinite gratitude towards my husband, Cory, who listened, reassured me, and picked up the slack.

Abstract

This action research study worked to determine how mastery experience, vicarious learning, and expert role models impacted the engineering self-efficacy of 113 6th grade science students. The students participated in a 3-week unit designing toy cars in small groups with lessons planned to improve their self-efficacy. The students were surveyed before and after the unit to show how their efficacy changed. They also completed an exit ticket to reflect on the unit and were observed as they worked with their peers to document examples of verbal self-efficacy. The study results indicated that the strategies used were successful in improving engineering self-efficacy.

Keywords: engineering, self-efficacy, mastery experience, vicarious learning, role models

Engineering is a highly specialized field that focuses on solving problems in the world around us. This career is integral to our society functioning smoothly as it creates new medical treatments, safe transport vehicles, and everyday technology for electronics, to name a few. It also provides many people with challenging and rewarding employment. While citizens of the United States reap the benefits of engineering daily, the country faces a shortage of engineers. Job markets do not have enough qualified applicants to fill the increased demand for engineering positions (Knezek et al., 2011).

All students can benefit from learning about professions in the engineering field. On the other hand, many students do not show interest or efficacy in engineering during the middle school years. Improving student self-efficacy in engineering during middle school is important because middle school is a formative time for students to determine their career paths and what classes to take in high school (Ogle et al., 2017; Samuels & Seymour, 2015). However, girls' confidence in themselves as engineers decreases in adolescence (Ogle et al., 2017).

Albert Bandura first introduced self-efficacy as, “A resilient sense of efficacy requires experience in overcoming obstacles through perseverant effort.” (Bandura, 1997, p. 80). The four main influences on self-efficacy are mastery experiences, vicarious experiences, verbal persuasion, and emotional state (Bandura, 1997; Hayden, 2013).

Because we know middle school is such an essential time for developing efficacy in engineering, the strategies to build efficacy must be intentionally implemented within engineering units. In this action research study, 113 6th-grade students participated in a unit planned to improve their engineering self-efficacy. These students came from a mixed rural and suburban community. The unit centered on building, designing, and testing a toy car through the engineering design cycle. Before the unit began, the school experienced a low number of students identifying interest in engineering as a future career. The teacher purposely implemented mastery experience, vicarious learning, and engineering role models within the unit to determine if those strategies would improve students' engineering efficacy. The project explored the question, how will mastery experiences, vicarious learning, and engineering role models impact engineering self-efficacy?

Theoretical Framework

Albert Bandura introduced the idea of self-efficacy in the context of Social Cognitive Theory (1997). He indicated that if people do not have self-efficacy in an area, they will not attempt the task (Bandura, 1997). Bandura reported, "A resilient sense of efficacy requires experience in overcoming obstacles through perseverant effort." (Bandura, 1997, p. 80). Self-efficacy differs from self-esteem because efficacy relates to beliefs about ability, while esteem refers to beliefs about worth (Bandura, 1997). Research into self-efficacy has identified the four main influences, as stated in the introduction: mastery experiences, vicarious experiences, verbal persuasion, and emotional state (Bandura, 1997; Hayden, 2013).

The absence of engineering self-efficacy in the 6th-grade science classroom triggered this action research project. When students were surveyed about future job choices, engineering was lacking representation in responses. Students have a natural tendency to want to solve the problems in the world around them. Engineering is a real-world application of that problem-solving nature. Having engineering self-efficacy is the first step in becoming an engineer, so Bandura's theories were a natural fit to plan an engineering unit that would increase engineering self-efficacy.

Bandura's theory of self-efficacy has helped teachers plan lessons with increased student efficacy in mind. All students can benefit from increased engineering self-efficacy because engineering is a problem-solving process. Because of this, many studies were conducted to show how to apply Bandura's theories to engineering lessons.

Review of Literature

Engineers are essential problem solvers in our communities. This job is highly demanding but allows workers to create more efficient and safer lives for local communities and the worldwide community. Engineering jobs are expected to grow four percent from 2014 to 2024, adding about 65,000 new jobs. Biomedical engineers, environmental engineers, and civil engineers will likely have faster growth of up to twenty-three percent (Bureau of Labor Statistics, 2016). Job markets do not have enough qualified applicants to fill the increased demand for engineering positions (Knezek et al., 2011).

Unfortunately, many students do not feel confident in their abilities to become engineers. Of 126 sixth-grade students surveyed in the 2019-2020 school year at a middle school in Iowa, only one sixth-grade student indicated that they hoped to be an engineer in the future (Danilson, 2019). In the same study, only four students identified science or engineering as something they like most about school. Only one of those students was a girl (Danilson, 2019). These data indicate that students do not envision themselves as engineers.

Self-Efficacy Theory

Albert Bandura introduced the idea of self-efficacy in Social Cognitive Theory (1997). He indicated that if people do not have self-efficacy in an area, they will not attempt the task (Bandura, 1997). Bandura reported, “A resilient sense of efficacy requires experience in overcoming obstacles through perseverant effort.” (Bandura, 1997, p. 80). Self-efficacy differs from self-esteem because efficacy relates to beliefs about ability, while esteem relates to beliefs about worth (Bandura, 1997).

Hayden summarized the theory succinctly, "Self-efficacy is the belief in one's own ability to successfully accomplish something" (2013, p. 15). Self-efficacy is subject-specific and does not generalize to all areas (Schunk, 2012). The four main influences on self-efficacy are mastery experiences, vicarious experiences, verbal persuasion, and emotional state (Bandura, 1997; Hayden, 2013).

The Importance of Engineering Self-Efficacy

Improving student self-efficacy in engineering during middle school is important because middle school is a formative time for students to determine their career paths and what classes to take in high school (Ogle et al., 2017; Samuels & Seymour, 2015). Unfortunately, girls' confidence in themselves as engineers decreases in adolescence (Ogle et al., 2017). One strategy to improve the number of people going into engineering fields is to introduce the content earlier and more universally. Aranda, Lie, and Guzey (2019) report that the Next Generation Science Standards (NGSS) implementation requires elementary and middle school teachers to teach engineering more often and in younger grades. Additionally, students having engineering experiences before college increases the chance they will have high self-efficacy in engineering (Zhou et al., 2017).

Bandura determined that "Efficacy beliefs predict occupational choices" (2001, p.188). If students have higher self-efficacy in engineering, they will be more likely to choose engineering as an occupation which helps our society fill the increasing number of engineering jobs.

Beyond filling gaps in the job market, engineering can be valuable to the community. Citizens who think critically, in the way engineers are taught to think, are more likely to make scientifically informed decisions. Engineering education also improves students' ability to problem-solve and interpret new data (Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012). Students can benefit from the skills used in engineering no matter which career they choose because these skills are universal. These skills include teamwork, problem-solving, and critical thinking (Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012; Samuels & Seymour, 2015).

Mastery Experiences

As engineering becomes more common in the younger grades, teachers can help foster students' engineering self-efficacy through multiple strategies. Bandura (1997) indicates the most influential source of self-efficacy is mastery experiences. Mastery experiences are experiences where students use tools and methods to solve complex and challenging problems (Bandura, 1997). One study that introduced seventy-two middle school girls to engineering through a fashion-based mastery experience found that their program increased their self-efficacy (Ogle et al., 2017). In a different two-week study, twenty-seven middle school students designed toys. Of those students involved, thirty percent were girls. Results indicated that an early introduction to engineering through a challenging toy design course positively impacted students' self-efficacy (Zhou et al., 2017). The Girls in Engineering, Mathematics, and Science (GEMS) program also found that framing STEM inquiry around topics such as a forensic mystery improved student interest in STEM fields (Dubetz & Wilson, 2013). Another summer program meant to increase secondary students' interest in engineering careers used lego robots to help create mastery experiences (Goonatilake & Bachnak, 2012). In these four studies, students experienced mastery in engineering and experienced engineering through high-interest topics (Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012; Ogle et al., 2017; Zhou et al., 2017).

Teachers can consider mastery experiences a positive strategy for fostering students' engineering efficacy (Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012; Ogle et al., 2017; Zhou et al., 2017). Teachers might also consider framing their engineering units around high-interest topics because it was successful in these studies (Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012; Ogle et al., 2017; Zhou et al., 2017).

Vicarious experiences

Another strategy that has been successful in improving engineering self-efficacy is vicarious experiences (Ogle et al., 2017; Zhou et al., 2017). Vicarious experiences are closely linked to social comparison. Vicarious experiences are those in which students can see peers modeling successful strategies for overcoming a problem (Bandura, 1997). Ogle et al. (2017) indicated that the fashion program's positive results might have been due to enthusiasm and collaboration between participants. Students in this study were able to see similar peers succeeding in engineering (Ogle et al., 2017).

The toy design study indicated that multiple vicarious experiences such as observing peers' model sketches and prototypes helped improve engineering self-efficacy among the twenty-four students that participated (Zhou et al., 2017). While many vicarious experiences were used, all involved students observed peers model a successful solution to one of the presented engineering problems (Zhou et al., 2017). Both of these studies show that students learning through vicarious experiences can help improve their engineering self-efficacy (Ogle et al., 2017; Zhou et al., 2017).

Exposure to Experts and Engineers

Finally, research indicates that exposure to engineers or experts in engineering can positively affect engineering self-efficacy (Degenhart et al., 2007; Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012; SciGirls 2020). Teachers might use this pattern to invite experts into their classrooms to share experiences and encourage learners. Degenhart et al. (2007) assigned a National Science Foundation graduate student to classrooms and observed a positive trend in student self-efficacy.

Female college students and professors in science and engineering ran the GEMS program (Dubetz & Wilson, 2013). This exposure to female experts allowed girls to see themselves as engineers (Dubetz & Wilson, 2013). Goonatilake & Bachnak's program focused more on exposure to STEM fields and experts, with one optional hands-on activity. Yet, students still thought more positively about STEM careers after the workshop (2012). The SciGirls program finds the same strategy of exposure to female STEM role models encourages girls to have a strong STEM identity (SciGirls, 2020).

These studies indicate that students who are exposed to experts, especially experts that they can connect with, will have a stronger STEM identity and increased self-efficacy in engineering. Those experts can be college students, college professors, or industry professionals (Degenhart et al., 2007; Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012; SciGirls 2020).

Summary

As a result of increased demands for engineers in our job market and benefits to students who master engineering skills, teachers should be preparing students to have high self-efficacy in the field (Bureau of Labor Statistics, 2016; Knezek et al., 2011). Current research on mastery experiences, vicarious experiences, and exposure to experts indicates that these strategies are all associated with improved self-efficacy in middle school students (Degenhart et al., 2007; Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012; Ogle et al., 2017; SciGirls, 2020; Sheu et al., 2018; Zhou et al., 2017). These seven sources show the many instructional strategies that help students improve their self-efficacy in engineering (Degenhart et al., 2007; Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012; Ogle et al., 2017; SciGirls, 2020; Sheu et al., 2018; Zhou et al., 2017).

The most common strategy that improved engineering self-efficacy, showing up in five out of the seven studies, was mastery experiences (Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012; Ogle et al., 2017; Sheu et al., 2018; Zhou et al., 2017). The next most common successful strategy, discussed in four of the seven sources, was exposure to experts in the field (Degenhart et al., 2007; Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012; SciGirls, 2020). Finally, two studies identified that vicarious learning improved engineering self-efficacy in middle school students (Ogle et al., 2017; Zhou et al., 2017).

Next Steps

Because mastery experiences, vicarious learning, and exposure to experts all show connections to improved engineering self-efficacy, the action research project will focus on those learning experiences (Degenhart et al., 2007; Dubetz & Wilson, 2013; Goonatilake & Bachnak, 2012; Ogle et al., 2017; SciGirls, 2020; Sheu et al., 2018; Zhou et al., 2017). This project will attempt to determine what impacts these learning experiences will have on the engineering self-efficacy of sixth-grade students.

Methodology

This study was approached through an action research and an experimental design process. Both qualitative and quantitative data were collected through multiple means in order to triangulate how planned mastery experiences, vicarious learning, and expert role modeling impacted student self-efficacy. The researcher collected participant self-efficacy scores through a preliminary five-point Likert scale which was repeated at the end of the unit. A reflective essay accompanied this in response to an exit ticket. During the unit, a guest teacher recorded examples of self-efficacy in the classroom using a tally sheet. A final piece of data was a lesson plan categorization tool that enumerated planned mastery experiences, vicarious learning, and expert role modeling.

The participants in this study were 6th-grade students. The study took place daily during the 45-minute science class across 16 days. One hundred thirteen students across five in-person sections participated in the study. The population consisted of 54 male students and 59 female students. This study was conducted during the spring of the 2020-2021 school year in suburban Iowa. At this point, students were coming to school in person all days of the week in a parent choice model. Students learning from home were given an alternative assignment and assessment, so their data is not compatible with the study.

The pre- and post-attitude survey was administered as a five-point Likert scale. Students responded to eight statements scoring them 1-5 representing strongly disagree to strongly agree, respectively. The complete list of questions is in Appendix A. This attitude assessment was developed with reference to Saint Catherine's University's survey "Student Attitudes Towards STEM and Computer Science" (2015). This instrument empowered students to report their self-efficacy in engineering in student-friendly language. The survey was administered two times, once before the unit and once after.

The exit ticket was administered at the same time as the post-survey. The students were asked to use the space to write a short journal entry about the following questions. How successfully do you think you can use the engineering design cycle now that you've completed the toy car project? What strategies or activities in the toy car project made you feel like a better engineer? The teacher informed students there were no wrong answers, so they should be as honest as possible. This enabled the researcher to collect students' engineering self-efficacy opinions in an open-ended approach.

The guest teacher evaluation occurred in two class periods three times during the unit. The guest teacher recorded the number of occurrences of three events in the classroom. The events were: A student shared their learning, a student showed efficacy in background knowledge, and a student cited a specific engineering strategy to solve a problem. This tool allowed for triangulation of data by showing more instances of engineering self-efficacy in the classroom.

The fourth data collection instrument, lesson plan categorization, proves how often mastery experiences, vicarious learning, and expert role modeling were used as students engineered a toy car. The completed lesson plan categorization tool is included in appendix B. This tool provided evidence that the correct strategies were implemented in the car engineering unit to improve engineering self-efficacy.

The teacher introduced the car engineering unit to students as an opportunity to learn more about engineering. The teacher explained that she would be collecting data to see how effective this unit was at helping the students feel as if they could become engineers. The teacher read aloud the questions from the pre-survey and asked students if they needed any clarification on those questions before answering them using the five-point Likert scale. Students then responded to the survey using a Google Form format.

Students then spent 16 days completing an engineering design project with a group of peers. The teacher assigned groups, keeping peers with others of the same gender. The teacher guided students through the engineering design process, including days designated to defining the problem, listing constraints, gathering customer data through a survey, brainstorming solutions, designing a prototype, and testing their solutions. Most students had received prior instruction on the engineering design process, but the challenges they faced were much simpler in nature, such as designing a marble ramp or a tin foil boat. This engineering design challenge asked students to develop a toy car that met customer preferences and could use a small motor and gear train to make the vehicle travel 3 meters in 3 seconds or less, climb a 15 degree 1-meter long ramp in 2 seconds or less, or climb a 30 degree 1-meter long ramp. These challenges were adapted from the Society of Automotive Engineers Motorized Toy Car Unit (2021).

The highlights of mastery experience in the study included lessons 5 and 6, where students were first tasked with attaching gears to their toy cars. This was an unfamiliar task that resulted in initial frustration for many students. Through preservant effort, students were able to work in a team to achieve their goal of attaching gear trains to their vehicles by the end of lesson 6. Lesson 8 involved the same style of mastery experience with the challenge of securing a motor and wheels to their gear train. Lesson 10 asked students to add compound gear trains to their cars; an initially challenging task that all groups achieved by the end of the car design process. Lesson 12 allowed students to create a 3D model of what they wanted the outside of their car to look like using 3D modeling software. This process required many points of trial and error, but the students could use the 3D printers at the end of the day to print their designs. Finally, days 13-15 were days to construct and test the prototype cars against the performance standards. They could choose a goal from making the vehicle travel 3 meters in 3 seconds or less, climbing a 15 degree 1-meter long ramp in 2 seconds or less, or climbing a 30 degree 1-meter long ramp. All groups worked through at least one of the performance standards successfully by the end of the unit. Some groups succeeded at all three performance standards.

Throughout the unit, specifically on days denoted in Appendix B, students could learn through vicarious experiences. Because vicarious learning is defined as experiences in which students can see peers modeling successful strategies for overcoming a problem (Bandura, 1997), students could learn vicariously during group time as they observed their classmates. The teacher intentionally planned more direct instances of vicarious learning in the lessons by apportioning time in class for sharing successes. During those 3-5 minute breaks, a group of students with great success at a challenge shared the details of their approach with the whole class. Other students were able to ask questions to learn from their peers' experiences as well.

Students had three opportunities to learn from expert role models. On the second day, the 6th-graders were introduced to two engineering students from the University of Minnesota-Duluth. Those students shared their experiences in engineering and discussed the projects they had persevered through throughout their time in college. One of the engineers showed students a tour of a chocolate engineering lab and gave students samples of the final engineered product. The other engineer on this day discussed her work on the rocketry team and the process of launching cameras high into the atmosphere. The 6th-grade students asked questions to the student engineers at the end of the class period. On day 5, Students had the opportunity to talk to high school girls planning to pursue engineering. They represented the Society of Women Engineers. This was a meet and greet for any student interested in pursuing engineering as a future career. On day 7, Students were visited electronically by the WiSE (Women in Science and Engineering) program from Iowa State University. They were able to discuss how engineering works and some favorite engineering jobs. Overall, students had the opportunity to interact with three female college-aged engineering role models, one male college-aged engineering role model, and five female high school students pursuing engineering.

The data from the pre- and post-survey was divided into eight groups corresponding to the eight survey questions individually. The pre and post-survey data for each question was then analyzed through a one-sided paired difference in means t-test to determine statistical significance in the reported changes. The exact process was undertaken for each question, comparing boys' final results with girls' final results. The teacher coded the exit ticket data based on recurring themes within student answers. Occurrences of those themes were counted to determine which strategy was most effective according to students' perceptions. The six sets of guest teacher observation reports were counted to show a difference in examples of peer-to-peer verbal self-efficacy discussions at the start, middle, and end of the car design unit. These forms of analysis helped determine how effective the planned strategies were at improving student engineering self-efficacy.

Analysis of Data

This action research project was designed to determine how mastery experience, vicarious learning, and expert role models impact student self-efficacy in engineering. The study involved students participating in a toy car engineering unit using the above three learning experiences. The data was triangulated through attitude surveys, exit tickets, tally sheets of behaviors in class, and the documentation of lesson plans using the three self-efficacy strategies.

Impacts on Self-Efficacy in the Student Population

The overarching question of the action research study addressed how self-efficacy changed for the class as a whole. The pre- and post-survey data best represented this. By comparing the data before intentionally implementing mastery experience, vicarious learning, and expert role modeling to the data from the end of the unit, it is possible to see how the strategies impacted student engineering self-efficacy.

The students were surveyed on the questions in Table 1. The sample size for all questions was 113. The t-scores were calculated using a one-sided paired difference in means test. In this t-test, the null hypothesis is $\mu Pre = \mu Post$ indicating that the survey results were the same before and after the unit. The alternative hypothesis is $\mu Pre < \mu Post$ for all statements except for Statement 3, engineering is too difficult for me to succeed., where the alternative hypothesis is $\mu Pre > \mu Post$. The alpha value for significance is .01. The result is significant if there is a 99% probability that this outcome is not happening by random chance.

Students showed a statistically significant change in attitude about engineering self-efficacy statements except for statements 3 and 6. The statement that showed the most considerable difference in means was, I can become an engineer in the future. This data indicates students' engineering self-efficacy was significantly improved during the toy car unit. The data for statement 3 also sticks out because it is a negative t-value. This occurred because it is the only statement that would decrease in score if students showed a trend of improved self-efficacy. The rest of the statements follow a positive correlation of increased reported survey scores, meaning an increase in self-efficacy. The statements that have the most robust evidence that the toy car engineering unit improved student engineering self-efficacy were statements 2 and 8, followed closely by statements 1 and 7. All four of these statements would be considered statistically significant at an alpha value of .001.

Table 1

Whole-Class Pre- and Post- Survey Comparison Statistics

Statement	Mean of Difference	Standard Deviation of Difference	t-value	P-Value
1. I can use the engineering design cycle to solve a problem.	0.4071	1.1389	3.7996	.0001
2. I can become an engineer in the future.	0.7876	1.0893	7.6859	.0000
3. Engineering is too difficult for me to succeed.	-0.2035	0.9651	-2.2419	.0130
4. In the future, I can become a better engineer.	0.3186	1.1281	3.0020	.0017
5. I am good at fixing things.	0.2920	0.9791	3.1707	.0010
6. I know what steps to use to solve an engineering problem.	0.2655	1.2749	2.2137	.0140
7. I can contribute good ideas to an engineering team.	0.3982	1.0652	3.9742	.0001
8. I can create a visual or physical model of my engineering ideas.	0.4779	1.1733	4.3294	.0000

Impacts on Self-Efficacy in Male and Female Students Separately

The researcher also hoped to determine how the same three self-efficacy strategies would impact the genders individually. The same paired difference in means test was used in the data analysis of male student attitudes. The same null and alternative hypotheses were used for each question. The male sample size was 54 students, and the female sample size was 59 students. Table 2 shows the statistical analysis of the male students' results on the survey, and Table 3 displays the same information for female students.

The male student data is a stark contrast to the whole class data. Statements 1, 2, and 8 were the only statements that showed statistically significant change during the unit at the .01 alpha value. The item with the lowest P-value, .0003, was I can become an engineer in the future, indicating that male students rated that statement more positively on the post-survey by a statistically significant amount. The question that showed the least amount of change was, I know what steps to use to solve an engineering problem. The statement still resulted in an average positive shift in self-efficacy, but not enough to reject the null hypothesis.

Table 2

Male Student Pre- and Post- Survey Comparison Statistics

Statement	Mean of Difference	Standard Deviation of Difference	t-value	P-Value
1. I can use the engineering design cycle to solve a problem.	0.3889	1.1883	2.4050	.0098
2. I can become an engineer in the future.	0.5741	1.1591	3.6396	.0003
3. Engineering is too difficult for me to succeed.	-0.1111	1.0218	-0.7991	.2140
4. In the future, I can become a better engineer.	0.2778	1.2040	1.6953	.0480
5. I am good at fixing things.	0.1667	0.8849	1.3841	.0860
6. I know what steps to use to solve an engineering problem.	0.0926	1.1699	0.5816	.2820
7. I can contribute good ideas to an engineering team.	0.3519	1.1681	2.2135	.0160
8. I can create a visual or physical model of my engineering ideas.	0.5000	1.1935	3.0784	.0016

The trend in the female students' data differs from the whole class and the male data because every statement resulted in a statistically significant change from the pre-survey to the post-survey. This is evidence that the use of mastery experience, vicarious learning, and expert role modeling in an engineering unit was more influential on girls' engineering self-efficacy than boys' engineering self-efficacy. This trend raises the question, Did male students show minor changes in engineering self-efficacy because their survey results started at a higher level of self-efficacy?

Table 3

Female Students Pre- and Post- Survey Comparison Statistics

Statement	Mean of Difference	Standard Deviation of Difference	t-value	P-Value
1. I can use the engineering design cycle to solve a problem.	0.4237	1.1018	2.9541	.0023
2. I can become an engineer in the future.	0.9831	0.9912	7.6180	.0000
3. Engineering is too difficult for me to succeed.	-0.2881	0.9107	-2.4303	.0091
4. In the future, I can become a better engineer.	0.3559	1.0629	2.5722	.0063
5. I am good at fixing things.	0.4068	1.0524	2.9690	.0022
6. I know what steps to use to solve an engineering problem.	0.4237	1.3545	2.4029	.0097
7. I can contribute good ideas to an engineering team.	0.4407	0.9697	3.4906	.0005
8. I can create a visual or physical model of my engineering ideas.	0.4576	1.1644	3.0187	.0019

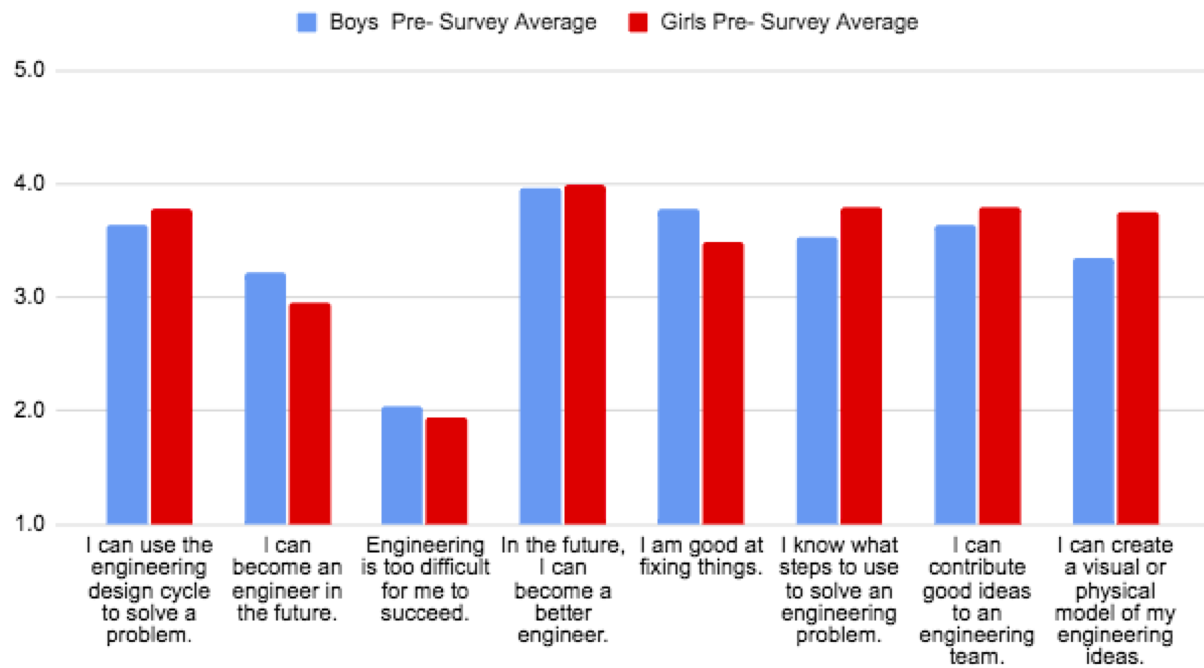
Starting Survey Results Gender Comparison

Because of the stark contrast between the male and female data, it is crucial to determine where the groups started. Suppose the male students reported higher self-efficacy in the pre-survey compared to the female students. In that case, researchers could explain why there were only three statements that showed statistically significant change for the boys compared to all eight statements showing statistically significant change for the girls. On the other hand, if there is no difference between the pre-survey scores of the groups, there must be another factor creating this difference between the populations. This portion of the data analysis will use means to compare the pre-survey responses for the male and female students. The male sample size was 54 students, and the female sample size was 59 students.

The data in Figure 1 shows no substantial difference in the pre-survey responses between male and female students. All of the averages are within .5 points difference between boys and girls. Statements 2 and 5 show initial stronger self-efficacy for the male students while the rest show initial stronger self-efficacy for the female students. The most significant difference was in response to, “I can create a visual or physical model of my engineering ideas.” Female students reported an average of 3.8, and male students reported an average of 3.4. The most negligible difference was .04 points in regards to the statement, “In the future, I can become a better engineer.”

Figure 1

Pre-survey Average Responses By Gender



Improving Self-Efficacy: Student Reports

The researcher also collected data through a free-response exit ticket. This exit ticket allowed students to report what strategies throughout the toy car unit helped them feel better engineers. Students were also able to report overall engineering self-efficacy by identifying if they thought they could use the engineering design process to solve problems. Responses to this exit ticket allowed for students to identify individual strategies that helped their engineering self-efficacy the most. This contrasts the data from the pre- and post-survey because that survey joined all the techniques together.

The exit ticket data separated strategies to determine what was most beneficial for students. The exit ticket data was coded by major themes within responses. Students reported that mastery experiences, vicarious learning, expert role models, and 3D modeling helped their self-efficacy the most. One hundred thirteen students responded to this exit ticket, and their data was compiled by percentages shown in Table 4.

A substantial majority of students, 89 percent, reported on their exit ticket that they felt confident in engineering because of the engineering design cycle. Almost half of the students, 46 percent, said that participating in planned mastery experiences throughout the unit helped their self-efficacy in engineering. Other themes that were present but not nearly as common were vicarious learning, role models, and 3D modeling. 3D modeling was not a strategy identified as improving engineering self-efficacy in past literature, but it was a common theme among study participants. One student reported, “When we were working on the 3D model, it made me feel like I could be good at this job, and I felt like I could maybe do it.”

Table 4

Student Reports: Self-Efficacy Percentages

Theme	Number and percent of students
Using the Engineering Design Cycle	101 (89%)
Mastery Experience	52 (46%)
Vicarious Learning	14 (12%)
Expert Role Models	18 (16%)
3D modeling and 3D printing	10 (9%)

Self-Efficacy Language Use

The final source of data was the tally sheets. These sheets allowed for the question, “Was there evidence during the class period that students used language that showed self-efficacy?” to be answered. This data was collected during 6 class periods throughout the unit. The information was collected at the start, middle, and end of the unit to determine if the language students were using showed self-efficacy more or less throughout the unit. The classes were combined, so the data in Table 5 shows the number of occurrences over an hour and a half as observed by one observer.

The data in the table shows the number of occurrences observed by the guest teacher stayed reasonably constant throughout the unit. Students were most likely to show self-efficacy in their background knowledge while discussing with their engineering team. Throughout four and a half hours of observation, the observer only heard one instance of a student citing a specific engineering strategy while talking to their peers.

Table 5

Number Of Occurrences Of Self-efficacy Language In The Toy Car Unit

Phrase	Start of the Unit	Middle of the Unit	End of the Unit
A student shares their learning. Ex. “I can show you how to…”	9	5	8
A student shows self-efficacy in background knowledge. Ex. “I know how to…”	24	25	20
A student cites a specific engineering strategy to solve a problem.	1	0	0

The data collected in this action research study shows an increase in self-efficacy as a whole. The data also indicates that the planned strategies of mastery experiences, vicarious learning, and expert role models were successful in helping students increase their engineering self-efficacy. While all the data showed a positive trend in engineering self-efficacy, most of the data showed this in a statistically significant manner.

Action Plan

This action research project aimed to determine how mastery experiences, vicarious learning, and expert role models impacted students' engineering self-efficacy. The 113 students who participated in this car engineering unit showed a statistically significant increase in engineering self-efficacy. Throughout the study, the data indicated that these strategies were helpful for students improving their engineering self-efficacy. Students reported that mastery experiences were most beneficial in enhancing their engineering self-efficacy of the planned strategies. Other methods that improved engineering self-efficacy were using the engineering design cycle and 3D modeling.

In regards to the engineering self-efficacy survey, all groups showed an increase in self-efficacy for every question. That increase was statistically significant at a .01 alpha level in 6 out of the eight questions for the whole grade level, eight of the eight questions for the female students, and three of the eight questions for the male students. This shows with 99 percent confidence that the strategies used in the engineering car unit made a positive impact on student's engineering self-efficacy. While all the survey results showed improved self-efficacy, it was surprising to see such a difference in significance between the male and female students. It was hypothesized that the males started with higher scores on the pre-survey resulting in less movement possible in the post-survey scores. This was not the case, so another factor must be causing the girls to show more improvement. It is possible that the expert role models being majority female and the teacher of the unit being female may have resulted in the more significant increases in female engineering self-efficacy.

The data in this study support the historical research in regards to self-efficacy. Bandura identified in his work on self-efficacy that the four main influences are mastery experiences, vicarious experiences, verbal persuasion, and emotional state (1997; Hayden, 2013). This action research study confirmed the positive influences of mastery experiences and vicarious experiences on engineering self-efficacy in middle school students. While Bandura also supports verbal persuasion and emotional states as strong influences on self-efficacy, this study did not measure those factors.

The most unexpected result from this study was 3D modeling as a common theme in the exit tickets. Nine percent of students reported that 3D modeling was one of the strategies or activities that helped them feel as if they were better engineers. 3D modeling may not have appeared in prior studies on engineering self-efficacy due to multiple factors. The most obvious of these is 3D printing is a new technology that was not around when Bandura first studied self-efficacy. Another factor could be the lack of access due to the costs associated with 3D printing. Finally, 3D modeling and 3D printing are tools that are specific to engineering self-efficacy, and Bandura and other researchers were looking at self-efficacy as a whole (1997). The positive value of 3D modeling can be used in any classroom with access to the internet and computers. 3D printing is more cost-prohibitive but a good investment in engineering self-efficacy for schools to consider.

Based on the results of this study, engineering teachers should be mindful of implementing mastery experiences, vicarious learning, and expert role models during engineering units. Teachers may also consider using 3D modeling programs and 3D printing as additional support for engineering self-efficacy. As more students experience positive engineering outcomes, they may fill the gaps in the engineering job market.

In the future, research could be planned to address the difference in male versus female results in the engineering self-efficacy survey. It would be good to see if a balance between male and female role models would help both groups improve their self-efficacy equally. This study could also be repeated with a male teacher leading the unit to determine if that impacts the gendered difference in self-efficacy.

Researchers may also consider designing a unit with a more purposeful connection to 3D printing and 3D modeling. As this technology becomes more common in schools, it would be prudent to determine how much it can help students increase their engineering self-efficacy. A short 2-3 day unit focusing on the process of 3D modeling and 3D printing in regards to engineering would be an intriguing short-term study.

This study confirmed the value of mastery experiences, vicarious learning, and expert role models when attempting to improve students' engineering self-efficacy. It also raised the question of how the gender of role models may influence self-efficacy. The action research project contributed to the wealth of knowledge, indicating that engineering self-efficacy can be improved using the three strategies studied. At the same time, it brought up using 3D modeling as an additional strategy to enhance students' engineering self-efficacy.

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Appendix A
Engineering Attitude Scale

Please read each statement and think about your life and how you feel. Do you agree or disagree with the statement? How strongly do you agree or disagree? For each statement, select a single number for each statement that is the best answer. There are no "right" or "wrong" answers!

Statement	1 Strongly Disagree	2	3	4	5 Strongly Agree
I can use the engineering design cycle to solve a problem.					
I can become an engineer in the future.					
Engineering is too difficult for me to succeed.					
In the future, I can become a better engineer.					
I am good at fixing things.					
I know what steps to use to solve an engineering problem.					
I can contribute good ideas to an engineering team.					
I can create a visual or physical model of my engineering ideas.					

Appendix B
Complete Lesson Plan Categorization Tool

Strategy Used	Mastery experience	Vicarious Learning	Exposure to engineers
Example entry	Students attempted three different ways to attach gears to the car to determine which works best.	Students watched one group model how a gear train works.	Students video conferenced with a local engineer.
Lesson 1		Students shared their problem statements and constraint list. Those students that shared had correct answers to what the problem statement and constraints were.	
Lesson 2			Students were given a presentation about engineering in college from the University of Minnesota: Duluth students. They were able to interact and ask questions.
Lesson 3			
Lesson 4		Students shared their customer survey with the whole class.	
Lesson 5	Students attempted multiple ways to attach gears to the car to determine which works best. By the end of class, students had their gears moving in a gear train on the car body.	Certain groups showed the class how the pieces of the car kit could go together to properly create a gear train.	Students had the opportunity today to talk to high school girls who are planning to pursue engineering. They represented the Society of Women Engineers.
Lesson 6	Groups use multiple strategies to try to calculate a gear ratio.	Groups shared how they calculated the most difficult gear ratios	
Lesson 7			Students were visited electronically by the WiSE program (Women in Science and

			Engineering) from Iowa State University. They were able to discuss how engineering works and some favorite engineering jobs.
Lesson 8	Students experimented with multiple ways to attach the motor and the car wheels to their toy car.		
Lesson 9		Students shared how they had found ways to attach the gears to the motor and the wheels.	
Lesson 10	Groups attempted multiple ways to create a compound gear train.	Certain groups talked to the class about how they created a compound gear train.	
Lesson 11			
Lesson 12	Students worked through multiple attempts at 3D modeling their car design.		
Lesson 13	Students attempted multiple ways to achieve the speed performance goal.	Successful students shared their designs with the class.	
Lesson 14	Students attempted multiple ways to achieve the climbing performance goal.	Successful students shared their designs with the class.	
Lesson 15	Students attempted multiple ways to achieve the climbing and speed performance goal.	Successful students shared their designs with the class.	
Lesson 16		Students shared their reflections on success with the class.	
Total number of times strategy is used	8	10	3