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A Self-Efficacy Analysis on the Impact of a Thermoelectric Cooling System Project in an Applied Thermodynamics Course

Dr. Krystal Corbett Cruse, Louisiana Tech University

Dr. Krystal Corbett is the First-Year Engineering Programs Coordinator and Assistant Professor in the Mechanical Engineering Department at Louisiana Tech University. She is also the Co-Director of the Office for Women in Science and Engineering at Louisiana Tech.

Mr. Casey Kidd, Louisiana Tech University

Casey Kidd is a graduate student in the College of Engineering at Louisiana Tech University. His focus is on project-based learning. He earned his bachelor's degree in mechanical engineering from Louisiana Tech University in Spring of 2004.

William C. Long, Louisiana Tech University

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Abstract

Engineering Technology programs provide students with an applications-based approach to learning technical content with the goal of better preparing students for the evolving demands of industry. Specifically, as society shifts more towards automation, providing graduates with expertise in sensors and calibration, programmable logic controllers, process troubleshooting, robotics and electrical power is critical. For an Instrumentation Control Systems Engineering Technology (ICET) Program at Louisiana Tech University, hands-on projects are consistently threaded throughout the curriculum resulting in graduates who can design, plan, research, evaluate, test and implement electrical and electromechanical systems that span multiple engineering disciplines.

To push the curriculum and its graduates forward, ICET faculty members are empowered to continuously develop and improve activities and projects for core courses. In Spring of 2022, a systems-level project was integrated into the sophomore-level Applied Thermodynamics course. A thermoelectric cooling system (TeCS) was developed in-house to allow students to experience and measure quantities related to the First Law of Thermodynamics.

The students purchased a low-cost TeCS kit consisting of individual components, which they assembled. Beginning in the first week, the students utilized the TeCS to apply thermodynamics concepts and continued to use it throughout the course. The students measured temperatures, air flow rates, mass, electrical current, and voltage to analyze the energy inputs and outputs of the system. The course material was designed to increase their understanding and intuition of fundamental principles through the hands-on projects related to their systems, culminating in a thorough analysis of the entire system.

This study assesses the impact of the TeCS on engineering self-efficacy using a validated pre- and post-survey. The survey addressed two main categories: general engineering and engineering skills, with the latter targeting the areas of experiments, tinkering, and design. The findings indicate statistical significance across both categories with the skills of design and tinkering exhibiting the most substantial significance. This paper will provide an analysis of the impact of the project on student self-efficacy throughout the course.

Background

In the engineering curriculum, thermodynamics concepts have historically been difficult for students to visualize. This was especially true with the traditional style of teaching, where the entirety of the course is presented to the students in a lecture format [1], [2]. It has been widely proven that incorporating hands-on learning into the course structure helps the students better understand and retain the concepts covered with the project [3]. The study presented in this paper is the follow-on work to the paper "A Thermoelectric Cooling Project to Improve Student Learning in an Engineering Technology Thermodynamics Course" [4]. The project detailed in that paper, and the subsequent analysis addressed in this paper, were implemented in the engineering course to help students better comprehend the core concepts that are central to the project. Cruse et al. provide a more in-depth description of the course and the project itself [4].

Other implementations of projects in thermodynamics courses have shown the effectiveness of projects in the classroom to varying degrees of success. Krishnan describes a project used in an introductory sophomore thermodynamics course, where the project was integrated into the lecture for a significant portion of the overall course grade. The students worked in groups of two or three to design an HVAC system for a typical single-family residence of a pre-determined size. At the end of the course, the students self-reported on their perceived mastery of the course contents. The results showed that they were somewhat satisfied with attaining the concepts [1]. Banerjee’s paper looks at the introduction of group projects in a thermodynamics course to improve the student's grasp of the basic course concepts. The groups applied basic thermodynamics principles to solve an engineering problem of their choosing. The researchers used two methods to assess the success of the projects. The first was a pre- and post-course questionnaire that had the students self-report on their attainment of the course outcomes. The second method was a comparative analysis of the student's performance before and after the application of the project. Analysis of both the questionnaire responses as well as the comparison of the grades indicates a positive influence of the group project on student learning and engagement [2].

The effectiveness of hands-on methodologies has been explored within the realm of engineering technology programs as well. In a computer-aided design/manufacturing course, Djassemi conducted a comprehensive pre- and post-survey analysis. The results indicated a notable improvement across all subject areas, with over 85% of students appraising the hands-on learning experience as either valuable or extremely valuable [5]. Similarly, Wang et al. observed parallel outcomes in their study on engineering technology students engaged in hands-on robotics activities. Their findings revealed that between 73% and 100% of students agreed or strongly agreed with survey questions probing the positive impacts of these hands-on activities [6]. Verma also demonstrated the constructive influence of hands-on activities on engineering technology students. Implementing a project-based learning approach in two first-year engineering and technology courses, Verma assigned groups of students Marine Kits for periodic use throughout the term. These kits facilitated various class activities, including exploring concepts such as a ship's kinetic energy, construction, stability, and more [7].

Hands-on applications are widely used throughout most courses within the Instrumentation Control Systems Engineering Technology (ICET) program at Louisiana Tech University. Of the core ICET courses, those that are managed or delivered by the program, over 85% have a hands-on or lab component. Recognizing that engineering technology students benefit greatly from hands-on applications, in conjunction with the difficulty in visualizing certain thermodynamics concepts, ICET faculty developed an engineering technology-specific thermodynamics project [4].

To assess the effectiveness of the thermodynamics project utilized in this study, the students completed a pre- and post-course survey that had them respond to multiple statements about their general and skill-specific engineering skills. These responses are used to determine the change in the student's self-perceived self-efficacy throughout the course. Self-efficacy is simply defined as a person’s perceived ability to perform a task [8]. Accurate self-efficacy can influence a person to make proper decisions and judgments daily, giving them considerable functional value. Studies have shown that an increase in self-efficacy can lead to multiple benefits, including increased effort to meet the demands of the situation and willingness to put in greater effort to obstacles. A person's belief in their efficacy can influence their choices, aspirations, and perseverance. In a study looking at the use of project-based learning in STEM courses, it was found that utilizing project-based learning resulted in an increase in greater STEM skills efficacy, which in turn resulted in higher levels of STEM career aspirations [9], [10]. A study conducted at Texas A&M University and Houston Community College used the engineering domain-specific self-efficacy instrument, validated by Mamaril [8], to illustrate the importance of using such an instrument for engineering and engineering technology students over a more general self-efficacy survey [11].

The expectation of the course project is that providing a hands-on experience targeted at increasing the students' understanding and grasp of difficult course concepts will positively influence their perceived engineering self-efficacy. The following hypothesis was generated to reflect this goal.

> *Hypothesis: Students who participate in the course project will demonstrate an increased engineering self-efficacy throughout the course.*

Course and Project Description

In the Spring of 2021, a pilot version of the TeCS project was introduced to fourteen ICET students. Before this academic term, the course followed a more traditional lecture style with occasional demonstration activities. Insights and lessons learned from this pilot implementation prompted enhancements in the project kit and course plan, resulting in a more comprehensive and well-rounded project for the Spring of 2022. The primary focus of this paper is to examine the impact of the 2022 version of the TeCS project on the self-efficacy of the students. This term is considered the first full implementation of the TeCS project. This course consisted of 24 ICET students.

The primary objective of the sophomore-level ICET curriculum is to establish a robust foundation in thermal concepts and measurements through immersive, application-focused content. To illustrate these principles, especially the First Law of Thermodynamics, ICET faculty members developed an in-house thermoelectric cooling system (TeCS) using cost-effective materials. When developing the TeCS project and course implementation, the design team identified key objectives. Specifically, they intended the project to enable students to actively engage with a system constructed from discrete parts, conduct physical measurements of thermodynamic variables, experience a systematic variation of the thermodynamic variables being measured, account for energy conversion from one form to another, and track energy to adhere to the principles of the First Law of Thermodynamics.

Each student acquired the TeCS project kit for $35, which served as an alternative to a traditional textbook. Their instructor provided all the necessary textbook materials. During the development and design of the TeCS, considerations were given to the students' prerequisite courses, allowing students to leverage their experiences in fabrication, circuitry, and programming to assemble their TeCS kits.

The TeCS comprised a thermoelectric element mounted on the top of an aluminum heat sink, with a thermally conductive pad positioned between the element and the heat sink. A 3D-printed flume, attached to a fan, was integrated to facilitate the airflow across the heat sink. Atop the thermoelectric cooling element, a container was placed to contain water or other substances undergoing cooling. Thermistors, coupled with an Arduino, were utilized to gather temperature measurements at crucial points within the TeCS. To aid in thermistor calibration and offer a quick reference for the temperature data of the analyzed substance, a digital thermometer was included. The system featured two toggle switches—one to control the thermoelectric element and the other to control the fan. A 12VDC power supply was connected to the system using a barrel jack. The full assembly of the TeCS is depicted in Figure 1. Cruse et al. provide a detailed description of the TeCS [4].

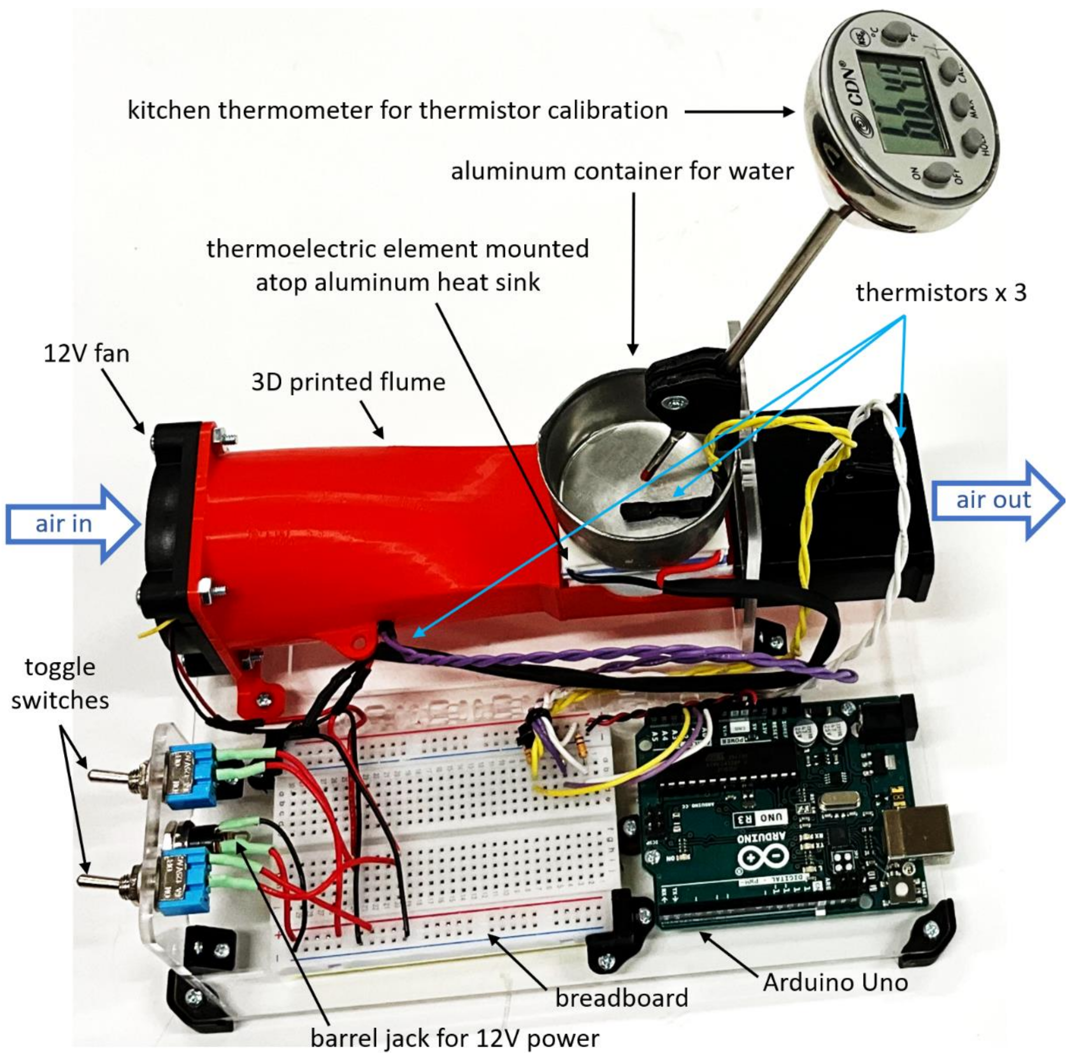

Figure 1. TeCS Project [4]

Throughout the course, students progressively advanced their activities with the TeCS. Among the 28-course meetings, nine days were predominantly dedicated to hands-on project applications. To ensure comprehension of the system and proper application of concepts, three major project checkpoints were strategically scheduled throughout the term. While the majority of activities centered around the energy balance, certain concepts extended beyond the applications of the First Law.

Students utilized the system to measure temperature during phase changes in a given substance, facilitating a connection between physical measurements, observations, and phase change diagrams. This experience enhanced their familiarity with the systems. While throughout the course, the TeCS featured in smaller activities, the primary emphasis remained on applying the First Law of Thermodynamics. To achieve this, students were required to measure temperature at key locations, employ multimeters for electrical energy measurements in their systems, and consider energy associated with airstream flow.

Students analyzed each component of their system individually in preparation for the culminating activity, which involved conducting a comprehensive analysis of the overall system. Cruse et al. provide a detailed overview of the course topics, with project days and activities denoted [4].

Survey And Data Collection

Researchers implemented a self-efficacy survey in the course structure to gain insights into the project's impact on student self-efficacy. The instrument used to measure self-efficacy was an adapted from of the survey validated and discussed in Mamaril et al.'s *Journal of Engineering Education* paper entitled, "Measuring Undergraduate Students' Engineering Self-Efficacy: A Validation Study [8]." In this validation study, a self-efficacy instrument was identified to measure engineering efficacy in four areas: general engineering (Gen) and three engineering skills of experimental (Exp), tinkering (Tink), and design (Des) through a twenty-five-question assessment.

For the purposes of this study, all twenty-five statements from the validated survey were included, with slight modifications to five of the statements. Two statements that referenced "semesters" were adapted to reference "quarters," Three statements in the tinkering self-efficacy section referenced "machines" which was replaced with "system and/or components and devices" to reflect the terminology used in the course.

Students were asked to indicate the level to which they agree with each statement using a five-point Likert scale, with responses ranging from "Definitely Not" with a scale value of one (1) to "Definitely Yes" with a scale value of five (5).

Table 1 lists the twenty-five statements the students were asked, with the five modified statements denoted with an asterisk. The survey was administered on the first and last day of the course, allowing for a comparison of pre- and post-course data. Of the twenty-four students enrolled in the course, sixteen response sets were valid for self-efficacy analysis due to missing pre- or post-survey data for specific students.

Table 1. List of Statements Used to Assess Self-Efficacy

General Engineering Self-Efficacy	
Gen-1	I can master the content in the engineering-related courses I am taking this quarter.*
Gen-2	I can master the content in even the most challenging engineering course.
Gen-3	I can do a good job on almost all my engineering coursework.
Gen-4	I can do an excellent job on engineering-related problems and tasks assigned this quarter.*
Gen-5	I can learn the content taught in my engineering-related courses.
Gen-6	I can earn a good grade in my engineering-related courses.
Engineering Skill Self-Efficacy (Experiments)	
Exp-1	I can perform experiments independently.
Exp-2	I can analyze data resulting from experiments.
Exp-3	I can orally communicate results of experiments.
Exp-4	I can communicate results of experiments in written form.
Exp-5	I can solve problems using a computer.
Engineering Skill Self-Efficacy (Tinkering)	
Tink-1	I can work with tools and use them to build things.
Tink-2	I can work with tools and use them to fix things.
Tink-3	I can work with systems made up of components and devices.*
Tink-4	I can build systems.*
Tink-5	I can fix systems.*
Tink-6	I can manipulate components and devices.
Tink-7	I can assemble things.
Tink-8	I can disassemble things.
Tink-9	I can apply technical concepts in engineering.
Engineering Skill Self-Efficacy (Design)	
Des-1	I can design new things.
Des-2	I can identify a design need.
Des-3	I can develop design solutions.
Des-4	I can evaluate a design.
Des-5	I can recognize changes needed for a design solution to work.
**Adapted questions to match university/course terminology.*	

Survey Results

To specifically determine which of the results were statistically significant, a t-test was utilized to compare the change in self-efficacy for every statement in the survey. Of the twenty-five statements included in the survey, ten showed significance with a p-value < 0.05, with an additional two statements showing significance with a p-value < 0.1. The percentage of positive significant responses is nearly half, totaling 48%. In addition to the individual category statements results, the responses for each respondent were averaged across all statements in each category to give a single response value for that category. A t-test was again utilized to assess the overall understanding of the four categories of statements. Remarkably, all four average results show a positive statistical significance with a p-value < 0.05. Table 2 summarizes the statistical analysis used to compare the results from the pre/post surveys.

Table 2. Self-Efficacy Analysis Results

Category		Pre-Course Mean	Post-Course Mean	Paired Mean	t-value	df	p-value
General Engineering	**Gen-1**	4.00	4.25	-0.25	-1.73	15	0.104
	Gen-2	3.50	3.81	-0.31	-1.78	15	**0.096‡**
	Gen-3	4.13	4.56	-0.44	-2.41	15	**0.029†**
	Gen-4	4.00	4.31	-0.31	-1.43	15	0.173
	Gen-5	4.31	4.63	-0.31	-1.58	15	0.136
	Gen-6	3.94	4.31	-0.38	-1.57	15	0.138
	Average	3.98	4.31	-0.33	-2.38	15	**0.031†**
Experiments	**Exp-1**	4.13	4.63	-0.50	-3.87	15	**0.002†**
	Exp-2	4.06	4.75	-0.69	-3.47	15	**0.003†**
	Exp-3	4.31	4.50	-0.19	-0.82	15	0.423
	Exp-4	4.25	4.38	-0.13	-0.70	15	0.497
	Exp-5	4.06	4.38	-0.31	-1.58	15	0.136
	Average	4.16	4.53	-0.36	-3.88	15	**0.001†**
Tinkering	**Tink-1**	4.81	4.94	-0.13	-1.00	15	0.333
	Tink-2	**4.88**	**4.75**	**0.13**	1.46	15	0.164
	Tink-3	4.44	4.88	-0.44	-2.41	15	**0.029†**
	Tink-4	4.31	4.75	-0.44	-2.15	15	**0.048†**
	Tink-5	4.00	4.69	-0.69	-2.71	15	**0.016†**
	Tink-6	4.13	4.56	-0.44	-1.96	15	**0.069‡**
	Tink-7	4.88	5.00	-0.13	-1.46	15	0.164
	Tink-8	4.81	5.00	-0.19	-1.38	15	0.188
	Tink-9	4.38	4.69	-0.31	-2.61	15	**0.02†**
	Average	4.51	4.81	-0.29	-3.75	15	**0.002†**
Design	**Des-1**	3.81	4.38	-0.56	-2.76	15	**0.014†**
	Des-2	3.81	4.56	-0.75	-3.22	15	**0.006†**
	Des-3	3.94	4.63	-0.69	-3.91	15	**0.001†**
	Des-4	4.13	4.50	-0.38	-1.70	15	0.111
	Des-5	4.13	4.44	-0.31	-1.58	15	0.136
	Average	3.96	4.50	-0.54	-3.50	15	**0.003†**

Key: †significant at α = 0.05 ‡significant at α = 0.1

As seen in Table 2, not every statement showed significance; however, there were at least two from each category that did show a positive change in the students' self-efficacy. Especially when adding in the average for each category, the overall increase in self-efficacy for all areas assessed is encouraging.

Discussion of Results

With a positive significant response of around 48% of the total responses, we believe we met our hypothesis defined for this project, if only just hitting the threshold. It can be challenging to see a widespread change in self-efficacy over a single term, yet we still received good results when analyzing the application of this project. With future improvements, we expect that success rate to increase even further. While the version of the project used in the course addressed in this paper yielded some positive results, we plan to continually improve the project for better performance in newer versions. With improvements in future iterations of the project we hope to increase the number of categories that show a positive significant result in the self-efficacy survey. When looking more closely at the positive results from this study, what begins to emerge is a good indicator of the project's success in the course with respect to increasing the students' engineering self-efficacy. Going section by section, the individual responses that showed statistically significant results can be analyzed in more depth. Unless otherwise stated, all data is being compared to a level of significance at 0.05.

The first category, General Engineering Self-Efficacy, is used to assess the students' perceived ability to master the content and coursework of the engineering course [8]. While the statements that addressed general course-specific content did not show significance (Gen-1 and Gen-4,5,6), the following statements did show a positive statistical significance.

- I can master the content in even the most challenging engineering course (Gen-2, $\alpha = 0.10$)
- I can do a good job on almost all my engineering coursework (Gen-3)

These two statements address the students' feelings towards their overall engineering ability in their courses. While this cannot be specifically attributed to this Thermodynamics course, it is a good indicator that the students' overall self-efficacy in their general engineering ability increased over the term, and this Thermodynamics course is certainly a part of that.

The first of the skill-specific categories, Experiments, showed a positive response with the following statements:

- I can perform experiments independently (Exp-1)
- I can analyze data resulting from experiments (Exp-2)

Significant responses to both statements indicate an increased confidence in the students' ability to perform and analyze experiments. This makes sense since this project aims to have the students perform measurements using their devices, analyze the results, and correlate those results to the content being taught in the course. The remaining three statements in this category of the survey, shown here, did not show statistically significant results:

- I can orally communicate results of experiments (Exp-3)
- I can communicate results of experiments in written form (Exp-4)
- I can solve problems using a computer (Exp-5)

The first two statements above, Exp-3 and Exp-4, address communication in the course. The lack of significance with these statements most likely indicates that there was not a heavy focus on communication in the course. This is one area where improvement can be made in future implementations of this or a similar project. The final statement in this category, Exp-5, addresses the students' use of a computer in the course. The lack of significant results with this statement is most likely due to the fact that the students are already comfortable using the computer in an engineering course environment, and therefore, there was no change in their self-efficacy through this course.

The next skill-specific category, Tinkering, showed the most significant responses from all categories in the study, with five of the nine statements showing positive significant results. However, before addressing these five statements, it is worth noting the first two statements in this category, Tink-1 and Tink-2, and why they might not have shown significant results. Those two statements are:

- I can work with tools and use them to build things. (Tink-1)
- I can work with tools and use them to fix things. (Tink-2)

This course takes place in the second year of the engineering curriculum after the students have spent the entire first year being introduced to and working with a majority of the tools they will be using throughout the curriculum. At this point, they most likely have already developed a familiarity with these tools and, therefore, did not have a significant increase in their confidence in using them. The five statements that did show positive significant results, Tink-3 through Tink-6 and Tink-9, are listed here:

- I can work with systems made up of components and devices. (Tink-3)
- I can build systems. (Tink-4)
- I can fix systems. (Tink-5)
- I can manipulate components and devices. (Tink-6, $\alpha = 0.10$)
- I can apply technical concepts in engineering. (Tink-9)

These statements address building and manipulating a project and all its associated components. As can be seen in the above description of the project, the students interact with many complex components, some of which they have not seen in previous courses. Through this project, the students were exposed to a more complex system. Additionally, they were required to apply more in-depth and technical concepts, which also helps explain the addition of the ninth statement, "*I can apply technical concepts in engineering* (Tink-9)," in the significant results.

The last two statements from this category that did not show significant results, Tink-7 and Tink-8, are listed here:

- I can assemble things (Tink-7)
- I can disassemble things (Tink-8)

Again, the students at this point in their curriculum have interacted with several course kits, through which they have assembled and disassembled multiple projects. Due to this familiarity, they most likely did not experience any significant change in their self-efficacy with these processes.

The analysis of the final skill-specific category, Design, also yielded promising results. Three of the five statements in this category showed positive significance:

- I can design new things (Des-1)
- I can identify a design need (Des-2)
- I can develop design solutions (Des-3)

The significance of these statements indicates that the students experienced an overall increase in confidence in their ability to identify a design need and follow through with a design solution. However, the last two statements in this category, Des-4 and Des-5 (shown below), did not indicate any significant increase in self-efficacy.

- I can evaluate a design (Des-4)
- I can recognize changes needed for a design solution to work (Des-5)

In this course there is no design challenge associated with the project, only the prescribed project build and associated analysis. To improve the project in future iterations, including an open-ended design challenge to the project will hopefully increase the student efficacy towards design change. Again, these are two areas that may have not been focused on through the project for this course and can be areas for improvement with future iterations of this project.

Conclusion

The engineering self-efficacy analysis of the TeCS project showed that the hands-on aspect of the project was successful in meeting the hypothesis set up at the onset of this research. Again, the stated hypothesis was:

> *Hypothesis: Students who participate in the course project will demonstrate an increased engineering self-efficacy throughout the course*

The results of the survey analysis showed that, of the twenty-five statements presented in the survey, nearly half of them yielded positive, significant results. This positive feedback included statements from every survey category, including the general engineering and skill-specific categories (skills include experimental, tinkering, and design). In addition to the individual statements, analysis of the average responses for the categories showed significant responses from every category in the survey.

The researchers are encouraged by the results of this study and the project's direct impact on engineering technology students. Identifying pedagogy and projects that help to positively increase the self-efficacy of engineering technology students is vital to their engagement and retention.

Future Work

Following the Spring 2022 offering of the course, further refinements were made for the Spring 2023 version of the course. The TeCS underwent a design overhaul, addressing a significant limitation identified during Spring 2022. The system's ability to dissipate heat and sustain measurable cooling over an extended period needed improvement. Consequently, a new design was developed, incorporating two fans to pass air over the heat sink, as opposed to the fan and flume that pushed air past it. This redesign enabled additional activities and provided a more robust design component for students to apply the thermal concepts they had learned. Additionally, in the third iteration of the project, familiarity with the project within the course structure allowed the instructor to incorporate automatic control through cascaded transistor/relay circuits and MOSFETs. A detailed description and analysis of the 2023 version of the TeCS project are anticipated in future work.

The authors also recognize the limitations of having a sample size of sixteen students. Using the t-test analysis provides greater confidence in the results. As the course is further developed, collecting more data from a larger population may yield further insights. Additionally, a control group could potentially add more depth to the study. While this preliminary study accounted only for the thermodynamics course that the students were taking at the time, a broader study could assess confounding variables such as concurrent and pre-requisite courses.

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