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A Thermoelectric Cooling Project to Improve Student Learning in an Engineering Technology Thermodynamics Course

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Abstract

Many engineering technology courses incorporate hands-on experiences to build intuition of fundamental topics and industry-relevant skills. A project was developed to enable the application of thermodynamic principles in a sophomore-level Instrumentation and Control Systems Engineering Technology (ICET) course. Each student taking the course purchased a low-cost kit that included a thermoelectric element, a heat sink, a fan, a 3D-printed flume, and supporting parts. Students assembled an Arduino-controlled thermoelectric heating and cooling system from the parts provided in their kit. Thermodynamics content in the course was woven around the project. Students measured temperatures, air flowrates, mass, electrical current, and voltage as they accounted for energy inputs and outputs of the system. The content was designed to build competency in fundamental topics through small projects with their systems, leading to a broader system analysis. The project's primary goal was to provide context for first-law concepts while building usable industry-relevant skills.

An end-of-course survey was also given to provide insights on the extent to which project elements reinforced targeted thermodynamics concepts. This paper will describe the project in detail, discuss the implementation of the project in the course, and provide an analysis of the project's impact on student learning of fundamental topics throughout the course.

Introduction/Literature Review

The importance of hands-on experiences in engineering education has been recognized for decades [1]. Despite this, in certain classes, such as thermal sciences courses, incorporating these experiences can be challenging. These classes tend to be taught in a traditional lecture format as a consequence. However, literature has shown that traditional lectures are passive learning experiences, leading to students losing interest in the course material and being less likely to comprehend the material at a deeper level [2]. Incorporating hands-on experiences in these traditionally lecture-style courses has the potential to bolster student understanding of abstract concepts and improve the attainment of achievement goals, although accomplishing this is not without its challenges.

Engineering technology students often struggle with thermal science concepts compared to other engineering concepts like statics. It is easier to visualize the transformation of potential to kinetic energy in simple mechanical systems than to visualize thermal energy conservation, as explained by the First Law of Thermodynamics [3,4]. As such, efforts have been undertaken to make thermodynamics more "visual" to provide more experiential learning. One such effort was applied to an introductory thermodynamics course where an overarching energy conversion topic was taught in tandem with the introduction of a hands-on experience using a heat exchanger.

After this experience, students indicated they were more confident in their technical knowledge, showcasing the advantages of incorporating hands-on activities in courses traditionally delivered via lecture [5]. These results connect to other literature that showed improved student understanding of concepts taught through project-based learning methods [6]. Another experiential learning example in thermodynamics had undergraduate students assisting with the installation of a solar photovoltaic array on a campus rooftop [7]. In addition to the installation, a graphical data interface was developed to read live solar energy data on laptops or smartphones. Evaluation of the project showed that students gained an appreciation for solar energy and its applications and fostered student confidence in their ability to improve solar panel performance. These findings aligned with research indicating that transformed classes motivate engineering technology students, improve classroom culture, and student learning potential [6]. Active learning pedagogies have been designed to provide students with opportunities to engage with the learning process as active participants, which promotes a deeper understanding of content and overcomes many of the disadvantages present in traditional lecture-based classes [2].

For an engineering technology program, such as ours, including experiential learning activities is imperative. A distinct aspect of engineering technology education is that it attracts students who prefer to learn experientially, as opposed to the theoretical approach often taken in engineering disciplines [8]. Consequently, engineering technology education pedagogy relies on hands-on laboratories and application work for a significant portion of a student's education.

Employers seek engineering technology graduates who have technical knowledge and judgment. To foster these skills, students need the chance to engage in open-ended assignments where the data is not always certain, and they have the opportunity to question the results of technical computations from established equations [7]. We considered ways to improve our technology students' understanding of fundamental concepts in thermodynamics and chose to adopt an active, experiential approach, as supported by the literature.

The design criteria for our project were as follows:

1. The project should include active engagement with a system built from discrete parts.
2. The project should involve physical measurement of thermodynamic variables.
3. The project should allow for systematic variation of these thermodynamic variables.
4. The project should allow for energy conversion from one form to another.
5. The project should facilitate the tracking of energy to satisfy the First Law of Thermodynamics.

This paper describes the implementation and assessment of this hands-on experience in a sophomore-level engineering technology thermodynamics course.

ICET at _______________ University

The Instrumentation and Control Systems Engineering Technology (ICET) Program at ________ ____________ University was established in 2017 in response to a regional need for graduates with engineering technical knowledge spanning electrical, mechanical, and instrument systems. The need for graduates with strong instrumentation and process control capabilities was also recognized due to the widespread adoption of advanced programmable control systems in local facilities. The new ICET program was adapted from a discontinued program, the Electrical Engineering Technology (ELET) Program. The content of the ICET curriculum was largely defined using the ABET ETAC criteria for Instrumentation and Control Systems Engineering Technology Programs. Baccalaureate degree programs are required to show that their curriculum includes “concepts of mechanics, fluid mechanics, and heat transfer to the design of process control systems. [9]” The ICET curriculum includes a thermodynamics course that focuses on first-law principles to provide a foundation for thermal concepts and measurements. While the ICET Program provides a strong introduction to fundamental topics in a number of areas, as in the case of thermodynamics, the focus of the Program is to present these fundamentals in an applied setting where students get their hands on sensors, parts, and systems to build intuition and industry-relevant skills in the area of instrumentation and control.

Project Description

The project, shown in Figure 1, includes a thermoelectric element mounted to the top of an aluminum heat sink using a thermally conductive pad. The thermoelectric element gets hot on one side and cold on the other when energized. An aluminum cup sits on top of the thermoelectric element. This container is filled with water that is either heated or cooled depending on the orientation of the thermoelectric element. The water is cooled when the cold side is up; when the hot side is up, the water is heated. Air drawn in on the left side by a 12-volt DC fan passes across the fins on the aluminum heat sink to either heat or cool the air. System performance depends on the ability to adequately remove heat on the hot side; the rate of heat removal is equal to the electrical power input plus the rate of heat extracted on the cold side.

Control of the system is accomplished manually using two toggle switches, one for the fan and the other for the thermoelectric element; automatic control could be provided through cascaded transistor/relay circuits or MOSFETs. Power is fed in through a barrel jack from a 12VDC power supply. Temperature is measured using three thermistors, one to measure the temperature of the water in the aluminum container and the others to measure the air's inlet and exit temperatures. Students can monitor the transient nature of the system's temperatures as it starts up and moves toward equilibrium. The breadboard is configured with a 12V side (the lower bus strip) and a 5V side (the upper bus strip) powered by the Arduino. This configuration reduces the chance of damage to the Arduino from the 12V supply.

Each student purchases a $35 parts kit to build the system in the class. Students must complete a significant amount of soldering as they wire in the toggle switches and the barrel jack. Ceramic insulating fabric is included to isolate the heat sink from the 3D-printed flume. The kit includes other parts not shown in Figure 1, such as an RGB LED to indicate water temperature, additional

LEDs to serve as indicator lights, and the wire and electrical resistors needed for the thermistor circuits. The 3D-printed and laser-cut acrylic parts are produced in-house.

To prepare for the soldering, students complete safety training followed by a safety agreement. They also complete safety training and a separate safety agreement related to the thermoelectric system operation. It is essential that students understand the potential safety hazards and acknowledge their agreement to fabricate and operate their systems safely. This project was designed for our particular educational environment; implementation elsewhere should evaluate potential safety hazards and provide safety guidance to adhere to the particular situation and local safety standards.

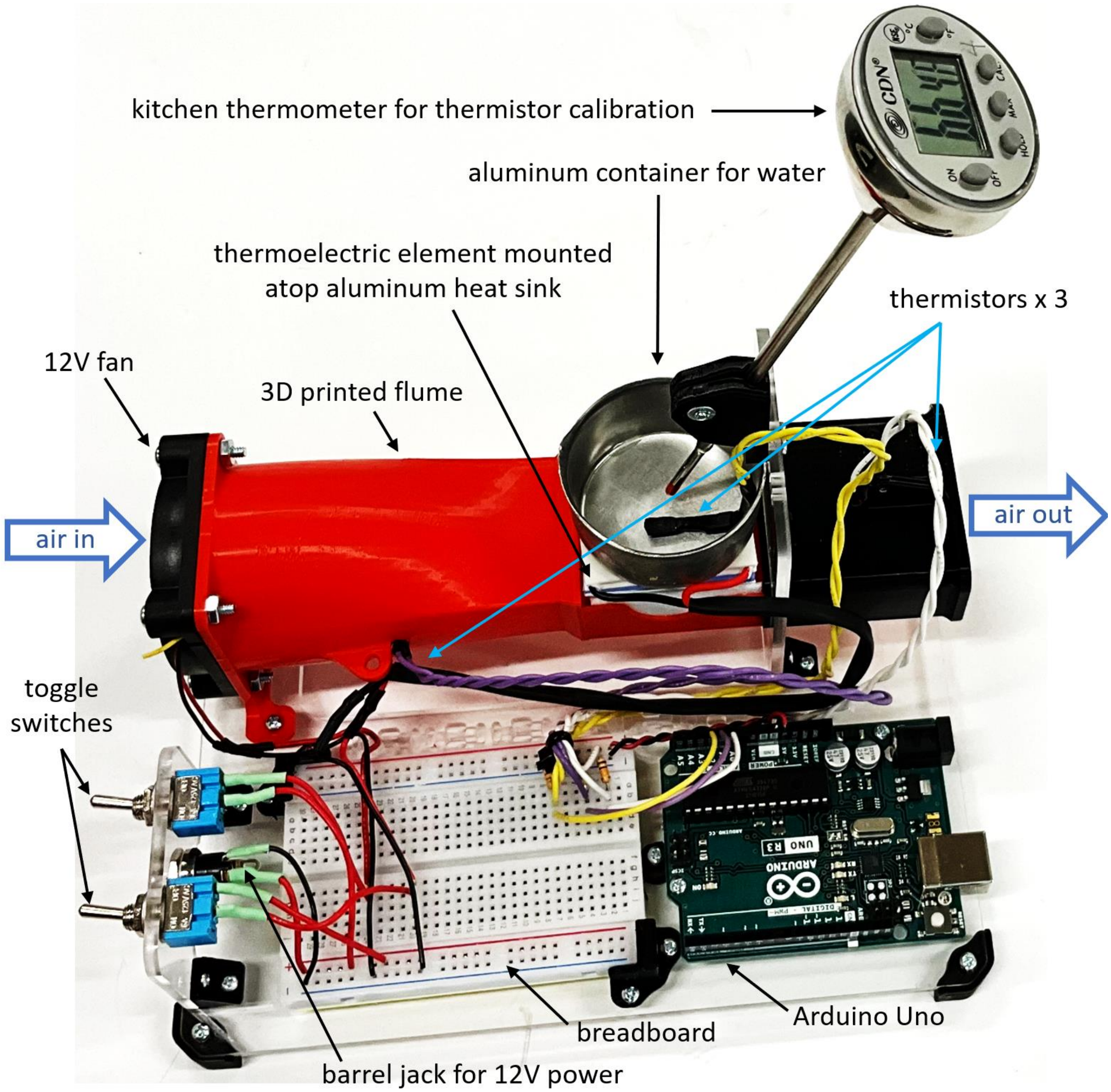

Figure 1. Thermoelectric heating and cooling project.

Thermodynamics Course Content

In the Spring of 2022, a hands-on thermoelectric cooling project in a thermodynamics lecture/lab course for the ICET Program at _______________ University was offered. The course was designed to build an intuitive understanding of the control of thermal systems through the lens of thermodynamics, specifically relating to first-law concepts.

Twenty-four students were enrolled in the 10-week sophomore-level course consisting of 28 class meetings lasting 110 minutes each. Course assessment included exams (50%), homework (15%), and projects (25%), with the remaining 10% allocated to professional development and participation. Students were given 16 homework assignments to build competency in thermodynamics fundamentals. The hands-on thermoelectric system project was introduced in Class 3 and interwoven throughout the course to connect thermodynamics topics to the hands-on applications of a control system. Three primary project checkpoints were incorporated into the course along with a final project activity to tie theory to application one last time at a systems level. Five exams were spaced evenly in the term to assess student comprehension and their ability to apply concepts. Table 1 provides a topical outline of the course along with milestones for the thermoelectric cooling project.

Table 1. ENGT 222 course content by class day (shaded rows indicate in-class project activities)

Day	Content	Homework/Project Assignments
1	Introduction to Thermodynamics	HW 1
2	Thermodynamic Systems	HW 2
3	Assembly of Thermoelectric System	HW 3
4	System Energy	HW 4
5	Thermistor Calibration – Day 1	HW 5
6	Thermistor Calibration – Day 2	HW 6 / Project Checkpoint 1
7	Heat and Work	
8	Exam 1	
9	First Law of Thermodynamics	HW 7
10	First Law Problems	HW 8
11	First Law Analysis of System Airflow	Project Checkpoint 2
12	Pure Substances and Phase Change	HW 9
13	Phase Change Experiments	Project Checkpoint 3
14	Exam 2	
15	Property Tables – Day 1	HW 10
16	Property Tables – Day 2	HW 11
17	Superheated Vapor and More!	HW 12
18	Exam 3	
19	Ideal Gas	HW 13
20	System Analysis	
21	Ideal Gas Problems	HW 14
22	Exam 4	
23	Closed Systems	HW 15

24	Specific Heat of Gasses	HW 16
25	Practice Problems	
26	Specific Heat of Solids and Liquids	
27	Exam 5	
28	Final Project Due, Wrap-up	Final Project Report

The thermodynamics project kit leveraged previous course content from the ICET Program's required first-year course sequence in which students learned circuitry, soldering, and Arduino programming. For example, in the first-year courses, students implement and calibrate thermistors, a critical component of the thermoelectric cooling project. After a quick review of the thermistors' circuitry, programming, and calibration procedure, the students integrated the sensors into their thermoelectric project. Similarly, the students used a fan with their Arduinos in a first-year course; having this previous experience allowed for easier and quicker integration of the fan and switches into the project.

The activities of the thermoelectric cooling system predominantly centered around understanding and applying the First Law energy balance. Students assessed various energy aspects of the system throughout the term and then connected these concepts to analyze the complete system at the end of the course.

An early project activity required the students to analyze the energy change of the air as it entered the fan and passed through the aluminum heatsink. Students inserted a hot wire anemometer into the wind tunnel to measure the air velocity. Additionally, they used their multimeter to measure the voltage and current required to drive the fan. Using this data, they calculated the rate of energy input to the fan, the mass flow rate of the air, the volumetric flow rate of the air, the rate of energy leaving the fan, and the efficiency of the fan system. In their report, they were required to explain any assumptions made, discuss why the fan is not 100% efficient, identify where energy was lost, and provide an energy pathway map for the system. In addition to energy balance, the thermoelectric cooling kit was used to perform phase change experiments. Students inserted a thermistor into the aluminum container filled with water and then placed the container into a freezer to convert the water to ice. Students then collected data as the ice melted (changed phase) due to heat being added to the system. This experiment allowed the students to explore and experience latent heat through a tangible application. They plotted temperature versus time and

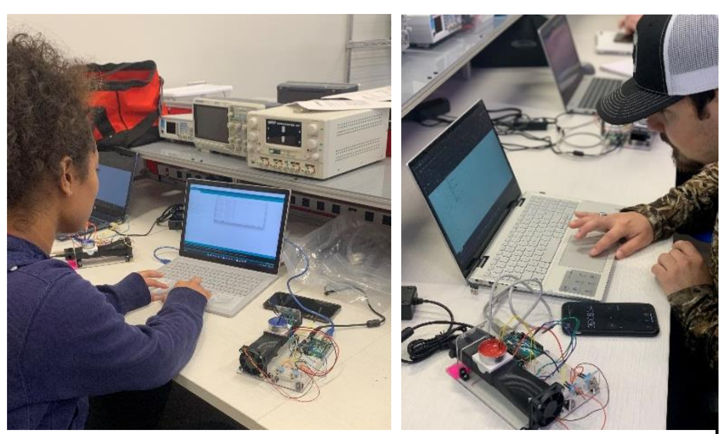

Figure 2. Students work on their projects during class.

compared their analysis and observations with phase change diagrams. Figure 2 shows students working on the phase change experiment during class.

At the end of the course, the students combined the various activities into a culminating analysis of the thermoelectric system. They demonstrated thermodynamic concepts by identifying the systems being analyzed. Figure 3 provides a worksheet that students used to define the thermodynamic systems and to track energy inputs, outputs, and losses.

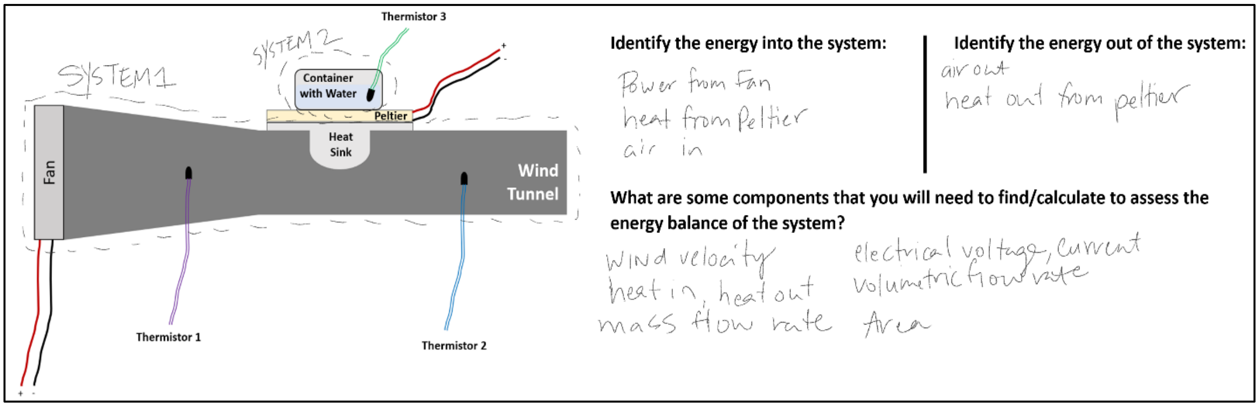

Figure 3. Student worksheet to define the system boundaries and identify energy in & out of the system.

Surveys And Survey Results

At the end of the course, the students were given a survey to assess the level to which they felt course outcomes were achieved and the benefit of the hands-on activities in learning the outcomes. Nineteen of the twenty-four students in the course completed the survey.

The End of Course Survey was divided into five parts:

A. How well they felt fundamental topics related to course outcomes were achieved.
B. The level of benefit that the hands-on activities provided in helping to learn each fundamental topic outcome.
C. How well they felt the applications related to course outcomes were achieved.
D. The level of benefit that the hands-on activities provided in helping to learn each application outcome.
E. Open-ended questions related to the structure, contents, and projects in the course.

Responses for sections A – D in the survey were in the form of 5-point Likert scale values. In sections A and C, students rated the level of achievement for each listed outcome with 1 - outcome not achieved at all, 2 - outcome only slightly achieved, 3 - outcome partially achieved, 4 - outcome mostly achieved, and 5 - outcome fully achieved. In sections B and D, students rated the level of benefit they felt the hands-on activities provided for each listed outcome with 1 – no benefit, 2 – very little benefit, 3 – some benefit, 4 – significant benefit, and 5 – essential benefit.

Table 2 summarizes the responses and provide statistical data related to sections A – D. Figures 4, 5, 6, and 7 illustrate the percentage of responses for the Likert scale category for sections A, B, C, and D, respectively.

Table 2. Summary of results from End of Course Survey Section A-D (N=19)

Section A. Fundamentals - How well they felt about …	Mean	Median	Mode	SD
1. Identify open and closed thermodynamics systems.	4.7	5	5	0.48
2. Identify work interactions and heat transfer between thermodynamic systems and their surroundings.	4.6	5	5	0.61
3. Apply simplifying assumptions in formulating and applying the concepts of heat, work, and energy.	4.5	5	5	0.51
4. Determine accurately the thermodynamics properties of simple compressible substances such as ideal gases and steam, as well as incompressible substances such as liquids.	4.5	5	5	0.70
5. Formulate and solve thermodynamic problems involving open and closed systems by applying the principles of conservation of mass, conservation of energy, and the second law of thermodynamics.	4.4	5	5	0.69
Section B. Fundamentals - The hands-on activities helped …	**Mean**	**Median**	**Mode**	**SD**
1. Identify open and closed thermodynamics systems.	4.2	4	4	0.48
2. Identify work interactions and heat transfer between thermodynamic systems and their surroundings.	4.2	4	4	0.61
3. Apply simplifying assumptions in formulating and applying the concepts of heat, work, and energy.	4.3	4	5	0.51
4. Determine accurately the thermodynamics properties of simple compressible substances such as ideal gases and steam, as well as incompressible substances such as liquids.	3.9	4	4	0.70
5. Formulate and solve thermodynamic problems involving open and closed systems by applying the principles of conservation of mass, conservation of energy, and the second law of thermodynamics.	4.2	4	4	0.69
Section C. Applications - How well they felt about…	**Mean**	**Median**	**Mode**	**SD**
1. Record and plot the temperature profile of water experiencing a phase change (liquid to vapor, boiling) in a time-series manner.	4.4	5	5	0.77
2. Implement thermoelectric device(s) (i.e., Peltier Coolers) in a closed-loop control system.	4.8	5	5	0.42
3. Implement instrumentation to various types of systems to analyze the system from a First Law perspective.	4.6	5	5	0.61
Section D. Applications - The hands-on activities helped …	**Mean**	**Median**	**Mode**	**SD**
1. Record and plot the temperature profile of water that is experiencing a phase change (liquid to vapor, boiling) in a time-series manner.	4.3	5	5	0.82

2. Implement thermoelectric device(s) (i.e., Peltier Coolers) in a closed-loop control system.	4.6	5	5	0.61
3. Implement instrumentation to various types of systems to analyze the system from a First Law perspective.	4.5	5	5	0.61

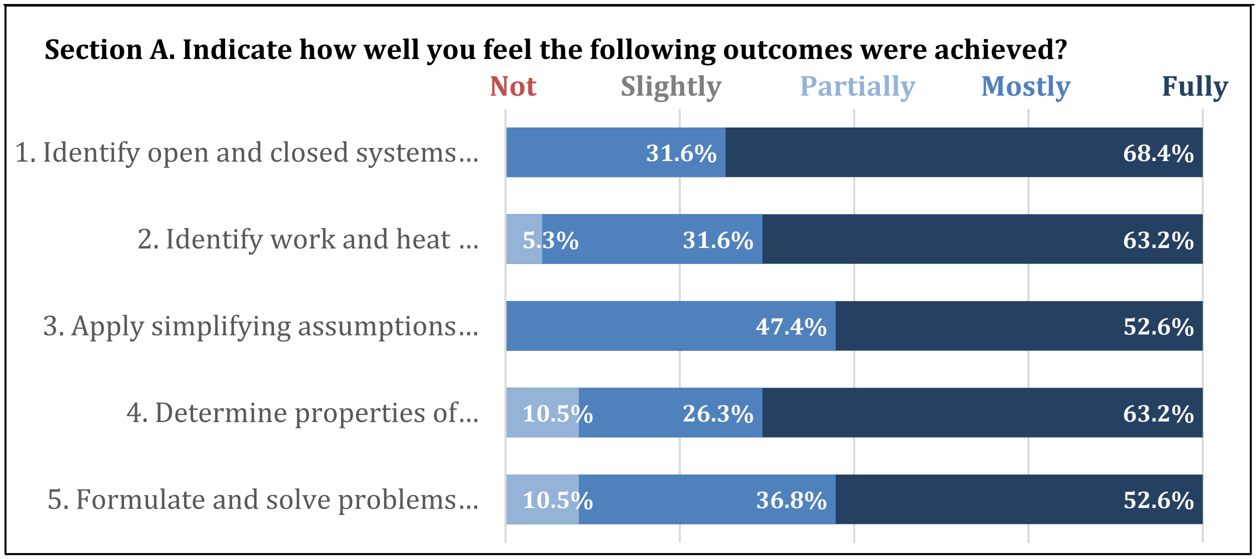

Figure 4. Percentage of responses for questions from End of Course Survey Section A

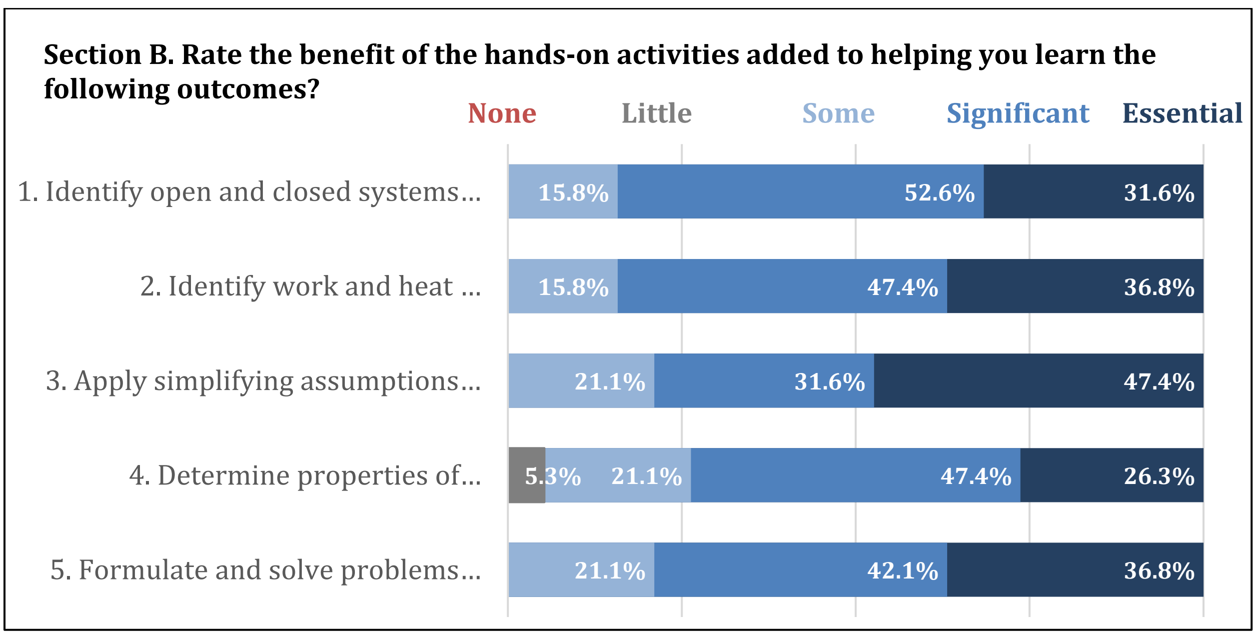

Figure 5. Percentage of responses for questions from End of Course Survey Section B

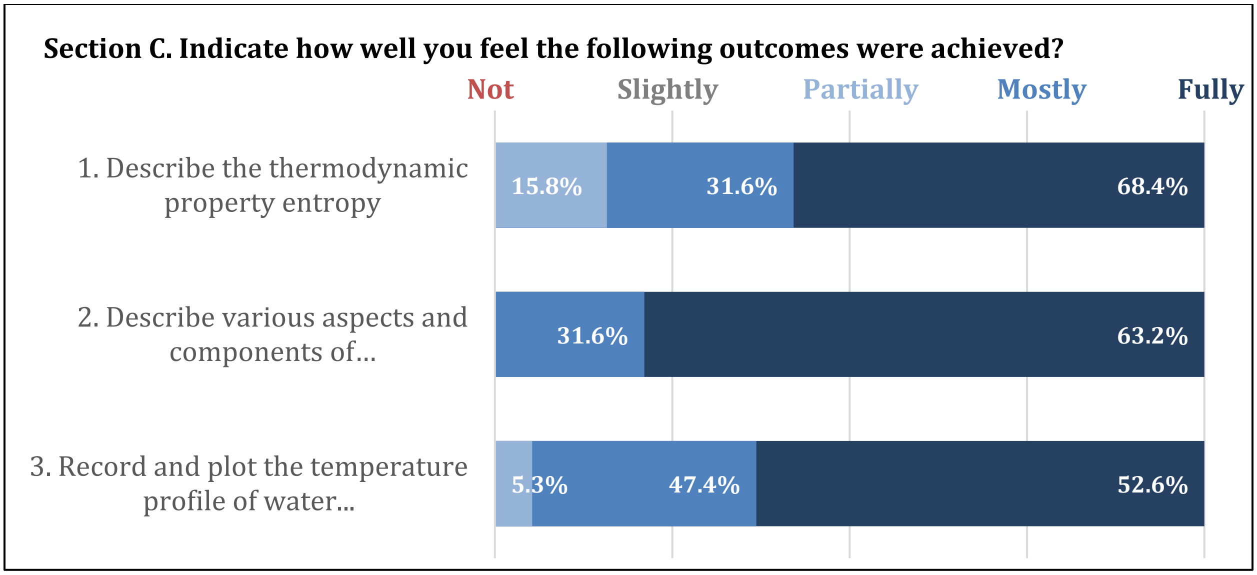

Figure 6. Percentage of responses for questions from End of Course Survey Section C

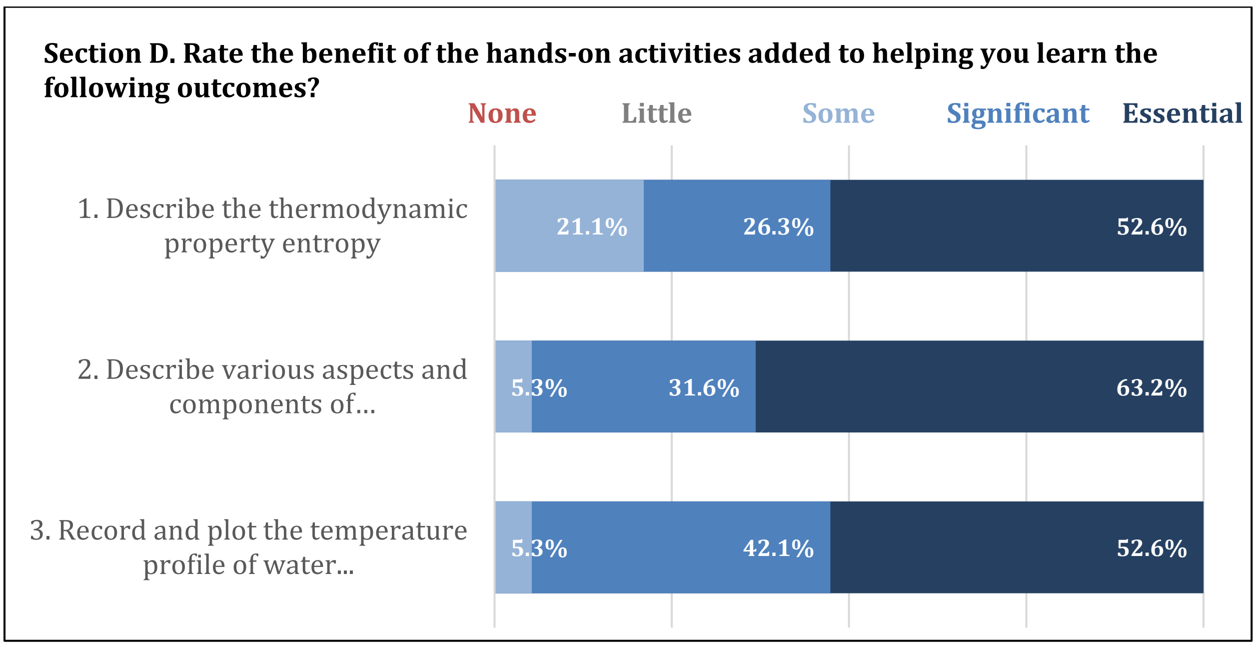

Figure 7. Percentage of responses for questions from End of Course Survey Section D

Overall, the responses to Sections A-D of the End of Course Survey were positive. The survey results indicate that the students felt the student outcomes related to fundamental topics (Section A) and applications (Section C) were mostly achieved with an average rating of 4.4 or higher. These responses can be mapped to "mostly achieved" and "fully achieved" rating categories. Furthermore, the students perceived the benefit of the hands-on activities in helping them understand the student outcomes on fundamental topics (Section B) and applications (Section D).

The students rated the benefit of the hands-on in Sections B and D at an average of 3.9 or higher, which is mapped to the "significant benefit" to "essential benefit" rating categories.
When assessing the lower end of the responses, only question B.4 was rated by one respondent as less than neutral. B.4 asked the students to rate the benefits of hands-on activity to "determine accurately the thermodynamics properties of simple compressible substances such as ideal gases and steam, as well as incompressible substances such as liquids." While these topics were covered, only incompressible substances were used in the thermoelectric project. Since there was no hands-on application with steam or ideal gases, this may have contributed to the discrepancy in scoring for the question, with some students focusing on the last line in the question prompt about liquids and rating accordingly. The student who responded negatively may have focused on the portion about steam and ideal gases, which could account for the negative response on how the hands-on activity benefit learning that particular concept.

For questions in Section B, most responses were on the positive end of rating options indicating "outcome fully achieved" or "essential benefit" for their respective sections. Four of the five questions in Section B of the survey, B.1, B.2, B.4, and B.5, had a higher percentage of responses in the second-tier positive level indicating only "significant benefit" for these questions related to hands-on activities. However, only question B.3 received a majority of responses indicating "essential benefit." This question asks specifically to rate the benefit of hands-on activities in helping to learn how to "apply simplifying assumptions in formulating and applying the concepts of heat, work, and energy." This fundamental topic is a significant focus of the course project. It is encouraging for future iterations of the project that students saw "essential benefit" related to this area.

Students were asked about outcomes related to applications in the class in sections C and D, where they rated how well they felt outcomes were achieved and the level of benefit the hands-on activities conducted in the class helped them learn about the application topic. The highest-rated questions were C.2 and D.2; these questions correspond with each other. C.2 asked them to rate the level to which the outcome of "implement[ing] thermoelectric device(s) (i.e., Peltier Coolers) in a closed-loop control system" was achieved and D.2 asked the students to rate the benefit of the hands-on activity in helping them learn the same outcome. All respondents to question C.2 rated this question a 4 or higher with 78.9% rating it at a 5 indicating the outcome was "fully achieved." All but one student rated D.2 a 4 or higher with 63.2% perceiving hands-on activities had an essential benefit to their learning about thermoelectric device(s) in a closed-loop control system. Additionally, C.3 and D.3 asked students to evaluate the achievement of the application and benefit of hands-on activities as they relate to "implement[ing] instrumentation to various types of systems to analyze the system from a First Law perspective." These two questions, which are essential to understanding the course project, were scored high. Given the results from C.2, C.3, D.2, and D.3, there is evidence to indicate that application outcomes relating to the thermoelectric cooling project were achieved and the student's perceived a benefit from the project in the course.

Section E of the End of Course Survey included five open-ended response questions which are listed in Table 3 with selected responses in italics under each question. These open-ended questions provide insights into the implementation of the thermoelectric cooling project which will help inform future iterations of the course.

Table 3. Questions and selected responses from Section E of the End of Course Survey

1. What did you like most about the course?
"I enjoyed getting to work on the project in class I enjoy hands on application."
"definitely the hands on activities"
"What I liked most about this course is using a hands on system to learn about thermodynamics."
"I enjoyed working on the Peltier cooler and learning how it affects a system."
"I generally enjoy learning about thermodynamics and how it makes me question previously held beliefs about things like heat and steam. I also liked how we constructed a compact system to help give us a visual representation of the concepts we were learning."
2. What did you like least about the course?
"The technical report on our project."
"I disliked the course in being the system we made had issues with the power and peltiers failing but that just comes with designing a new system."
"Energy balance equations, in my opinion, were the hardest thing to learn. It was made easier by being able to look at the system and identifying which sections contributed to the equation, but I still sometimes have trouble properly identifying certain work or heat being put into the system."
3. What hardware, software, prototyping equipment, and other resources did you use as part of this course?
Excel, Laptop, Soldering Iron, Calculator, Arduino, Multimeter, Mathcad, Thermistor, Peltier Cooler, Fan, Basic tools, Switches, Wires, Resistors, Screws, Acrylic platforms, Flow sensor (combination of multiple student responses)
4. What resources do you wish were available to help you with the activities and projects in this course?
"possible reference material for system outcomes to make sure we as students are getting correct values"
5. Do you have any suggestions for improving the course?
"A splash shield between the peltier and arduino seems like a good idea. To avoid spilling water on arduino during thermistor calibration."
"More in class examples"

Responses from E.1 could be categorized into three areas project, instruction style, and general content. Figure 8 shows the frequency of responses to E.1 in the identified areas. Some responses included comments that were categorized in multiple buckets. From this frequency analysis, it is evident that the students found the project to be what they liked most about the course.

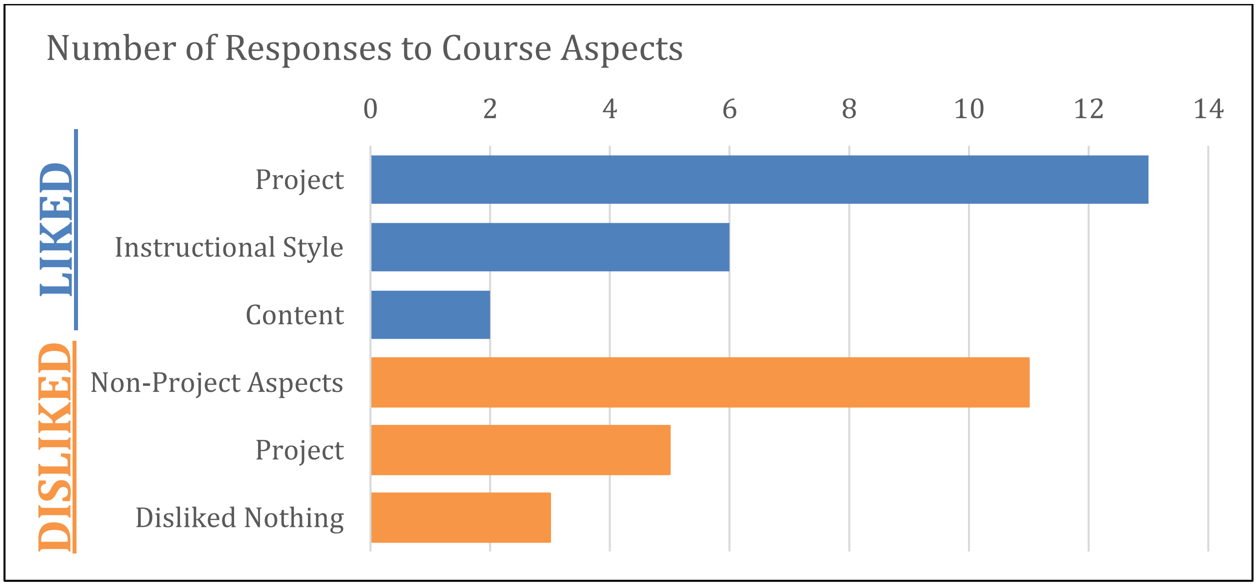

Figure 8. Frequency of responses for what students most liked in the course

Responses from E.2, which asked the students what they liked least about the course, were divided into project versus non-project. Figure 8 illustrates the division of project versus non-project-related dislikes with a third category for responses that said there was nothing they disliked. From this analysis, it is evident that aspects outside of the project contributed to more of the things they disliked in the course. Some components cited were homework, feeling rushed, and long workout problems. As shown in Table 3, one respondent mentioned they disliked energy balance equations the most but found the project helped them understand the concept better.

Conclusions

The thermoelectric cooling project provided engineering technology students with a tangible application of the First Law of Thermodynamics. Through this hands-on platform, students built a working thermoelectric cooling system from a collection of discrete parts. Students measured the temperature of air and water, the flow rate of air, and electrical voltage and current as they tracked the conversion and movement of energy through the system. The system involved significant energy loss that the student quantified by applying the First Law of Thermodynamics. Survey data indicate that the students felt the project was beneficial in helping them course concepts. The project will be revised and used in future offerings of the course.

References

[1] Canino, J.J. and Koch, J. "Improving student motivation using a 3D Printed Heat Exchanger", 2021 ASEE Virtual Annual Conference, ASEE 2021

[2] Ayoobi, M., Ssemakula, M, Djuric, A. "Effectiveness of evidence-based active learning pedagogies in engineering technology courses", ASME 2018 International Mechanical Engineering Congress and Exposition, IMECE 2018

[3] Cooper, H. "Using projects to improve understanding of introductory thermal science concepts", ASEE 2004 Annual Conference and Exposition, 2004, 15141 - 15146.

[4] Edwards, R. and Sun, L. " Developing in class experiments for fluid and thermal science courses for technology students", 123rd ASEE Annual Conference and Exposition, 2016

[5] Lugowski, J. and Hutzel, W. "Integrated learning in context for heat exchanger analysis". 125th ASEE Annual Conference and Exposition, 2018

[6] Maynard, C. Newell, B., Lucietto, A., Hutzel, W., Garcia-Bravo, J. "Applied Learning with Thermodynamics: A Perspective on Energy Concepts", 48th Frontiers in Education Conference, FIE 2018.

[7] Hutzel, W. and Loguwski, J. T., "Modernized teaching methods for solar energy projects", 125th ASEE Annual Conference and Exposition, 2018

[8] Fox, P., Sorge, B., Gordon, M.E., Danielson, S., Land, R., Richmond, N.,I., Perry, T.J., Gaines, K.W., Irwin. J., "What is the future of engineering technology?", *Journal of Engineering Technology*, 2020, 37(2), 48-59

[9] ABET Engineering Technology Accreditation Commission, Criteria for Accrediting Engineering Technology Programs, Baltimore: ABET, 2022.