Enhancing Thermodynamics Learning with a Modified Lab Experiment

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Abstract

Specific heat is one of the difficult topics in thermodynamics. Due to its abstract concept and theoretical nature, students could easily get lost during a typical PowerPoint lecture and found it difficult to solve related problems in homework and exams. Even when students could follow the steps to finish their homework, they felt challenged to connect the concept with real-life applications. It showed that the passive learning format is not effective in teaching this subject. To improve the student learning, we added an active learning element in the lab portion of the course by modifying some of the experiments. In many published conference papers, the active learning has shown being effective in improving student learning. In this paper, we would like to share with our ASEE community with what we did and learned from this work, and to seek feedback on this newly established active learning approach for our future research activities in other engineering courses.

The lab component of this course consists of about 10 different experiments. Once a week, students were divided into small sections and conduct the experiments under the guidance of the lab instructor. The active learning element was added after the experiment on latent heat. Upon completing this latent heat experiment, students were asked to design a new lab experiment to measure the specific heat of several commonly used construction materials and by using the measurement tools they learned from the just finished latent heat experiment. Once the measurement data were collected, they were asked to conduct related analysis and answer questions designed to reflect their understanding of the concepts and the ability to draw meaningful conclusions. This new lab experiment also fulfills one of the seven ABET learning outcome assessment requirements.

Before this new student-designed lab experiment on specific heat, a FE type quiz was given to the students during the lecture time. After the new lab experiment, the students were tested again with a similar quiz to gauge the improvement on their learning. Another survey question was also given before and after the new lab experiment to assess their understanding of the concept from the students' perspective.

The before and after quiz results showed 20% improvement on students' problem-solving skills related to specific heat. 95% of the students felt that, after this new and student designed experiment, they had a much better understanding on the topic.

Introduction

The most important goal of engineering education is to help students not only understand the mathematical and physical equations of the engineering concepts but also their real-life applications. To bridge the gap between the equations and the real-life applications and enhance understanding of the concepts, lab experiments have been added as integral parts of many engineering curriculums aimed at assisting students' learning and applying engineering concepts. Lab classes are more easily to provide an active learning environment [1] because students need to actively perform the experiments, collect the data, and explain and analyze the data they collected by themselves with the theories they were taught in class. Contrast to traditional in class lecturing as a passive learning style, active learning environment makes the students feel a sense of ownership, confidence, capability, competence, self-esteem, and enables them to meet life's challenge more effectively [2]. Active learning has been studied widely and proved effective in enhancing students' learning ([3], [4], [5]).

Comparing to the traditional lecturing in class, students in lab classes are more active. However, most of the traditional lab classes require students to passively follow the lab manuals made by the instructors to perform the experiments, so called a cookbook lab. Sometimes, some students don't understand the purpose of the experiments and the logic of the designed experimental steps besides simply follow the steps. It is still a passive learning experience for those students. To make students master the lab experiments, the lab classes need to be more active. One of the recent trends in using lab experiments to enhance student learning is to let the students design their own experiments. Myers and Burgess [6] found that the learning effects of those students who were in both lecturing class and their new inquiry-based (students design experiments) lab class are improved in solving complex questions comparing to the students who were only in the lecturing classes. McNeal [7] recommended three different methods to involve students in experimental design. Alvarado [8] described a self-guided problem-based lab activity in teaching thermodynamics in the engineering technology program. Yesilevskiy [9] reported a new experiment design format in their effort of transitioning from a passive learning environment to an active learning space by letting students construct their own lab experiments. They all found that students design experiments class are effective in improving students' learning.

Based on authors' observation, the students in this class grow up in a very different age as the instructors. Students designing their own lab experiments would more easily to bridge the gap because they use their own way of understanding to design their own experiments.

In summary, students designed experiments class is a more active learning environment which could enhance students' learning by actively involving students in learning the specific topics, designing the experiments based on their own understanding and their way of thinking, performing their own experiments, and analyzing their findings, and making meaningful conclusions according to their design. Besides enhancing students' learning, it also fulfills number six of the seven student learning outcome requirements from ABET Criterion 2 [10]:

6. *an ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering judgment to draw conclusions.*

The traditional lab experiments can do a good job in letting students conduct experiments and interpret results. On the other hand, it is very easy to neglect the "develop" part. Without this part, students mechanically follow the instructions and repeat the predetermined lab activities. When comes to the "develop" part, students must demonstrate their ability to design and develop the lab activities with minimum guidance.

Students designing experiment and performing it will require students to develop and conduct experiment, to analyze and interpret the data they collected, and then to use the engineering theories learned in class to draw conclusions.

Specific Heat is one of the course learning outcomes of Thermodynamics, a required course for all mechanical engineering majors. Students seemed to struggle in understanding the concept and mastering the associated problem-solving skills, based on instructor's observations on both homework and exams over the years.

Specific Heat is an important topic in thermal fluid curriculum with wide range real-life applications. It attracted attention among researchers and educators for many years. For example, in their study on forest fire prevention, Hasburgh and Boardman's work [11] showed that the specific heat capacity of red oak and Douglas fir becomes nearly constant with increasing temperature once pyrolysis starts. To help students better understand the concept, Mueller [12] developed a computer model to help students to study the temperature-dependent characteristics of specific heat on the isentropic compression of a gas. Herrington [13] modified a lab experiment to assist students make better connections between their personal experiences and the definitions and mathematical equations related to the concept of Specific Heat.

This type of research went beyond Specific Heat and covered the broad area of thermal fluid science to help students master the thermodynamics concepts. Based on their survey results, Robbins and Ardebili [14] saw that after traditional physics instruction many engineering students had not emerged with an effective understanding that would prepare them for a course in engineering thermodynamics. Various innovative teaching methods were employed in teaching this course, such as the active learning method by Georgiou and Sharma [15] and the numerical method by Ngabonziza and Delcham [16]. A more comprehensive review of such effort can be found in [17] and [18].

This Thermodynamics course has a lab component, where students conduct weekly experiments to support their learning. Among the various lab experiments, Specific Heat was not on the list.
To help students to learn the subject more effectively and to fulfill the ABET students learning outcome requirements, we decided to add a new lab experiment: a students designed lab experiment to reinforce the learning related to this topic and to fulfil the ABET students learning outcome assessment requirement.

Instead of following lab instructor's detailed lab instructions to perform the lab, this new student designed experiment lab class requires the students develop their own lab, then following their own design of the lab, perform it, collect data and analyze the data to reach the learning goal assigned by the lab instructor. The new lab format turns passively following instructions to actively develop their own experiments, verify their design, actively correct their design if needed during performing the experiments, then analyze their data to answer questions and draw conclusions. The quizzes showed a 20% improvement in students' problem-solving skills related to the Specific Heat analysis. The surveys also showed a 14% improvement in students' understanding of both the concept and the real-life applications of Specific Heat as the result of this newly added lab and its new approach.

Methodology

McNeal et al [7] provided three different approaches involving students in experimental design: one is to require students to read relevant literature and classic techniques to design their experiments, the second one is to let students design the experiments with the provided "design framework", and the third one is to let students design good protocols to answer questions from the given equations or problems. The method used in the new added students design experiment is a combination of the second and the third approaches.

Experimental apparatus (Fig. 1) was given to students, students have used the same equipment in their previous experiment related to the law of conservation of energy, which helped the students to know how to use the equipment.

The new lab was to assign students to work as a group to design experiments to measure the specific heat of five different widely used construction materials: metal, glass, wood, plastics, and concrete (Fig. 2) with the lab equipment they have used in previous labs with the theory of conservation of energy. The new lab was separated into three steps in a three-week period.

During the first week, students were asked to plan the experiment, which included the purpose of the lab, the list of lab equipment, list of lab materials, detailed experiment procedures, the data to be collected, and the goals to reach, in a group of three or four students.

During the second week, the group worked on their designed experiments: performed the experiments developed by the group, collected the data, and analyzed the data. Students were asked to observe the phenomena closely and to document the process by taking notes and photos.

During the third week, students analyzed their data together, discussed to answer the list of the questions assigned and draw conclusions together as a group. However, each student wrote their own report to document the experimental design, experimental procedure, data analysis, conclusions, and answers to the questions listed in Table 3.

Fig. 1 Experimental Equipment

Fig. 2 Construction Materials

Table 3. Questions to answer after lab was done.

1.	What is the specific heat of these five materials?
2	List the five materials in sequence from low to high and explain the physical meaning of a material with relatively low specific heat and a material with high specific heat value.
3	Give two real life examples of applying low and high specific heat materials in construction.
4	Riverside in southern California is going to make outdoor benches at public bus stops, which one among these five materials you will choose to use? Explain your choice?
5	Do you think metal is a good choice to build a house in Anchorage? Explain your answer.
6	Why is the temperature in coastal area more stable than that of the desert area?
7	Which material you would like to use as utensil handles? Why?

100% students actively participate the designing, performing, and discussion portion of the lab. However, only 90% of the students turned in their individual lab report. Among the 90% of the total students who turned in their lab report, 93% of the students answered all given questions correctly and drew a meaningful conclusion. The rest 7% of the students either did not answer all the questions, did not answer all questions correctly or did not draw a meaningful conclusion.

Results and Discussion

Overall, the lab activities went smoothly. Students were more excited on being able to design and conduct the experiment by themselves. As mentioned earlier, they were quite familiar with the thermodynamics lab setting from the previous lab experiment sessions and the commonly used equipment. Therefore, after understanding the tasks, they got on with the lab assignment quickly. Other than a few minor equipment related issues, which were resolved by the lab instructor, all groups finished the lab on time.

During the entire process, the lab instructor worked with the lecture instructor on a coordinated step. First, the lecture instructor conducted a survey and a quiz two weeks after the chapter on Specific Heat. The quiz contained two easy questions and one relatively hard question on the topic. The survey asked if they understood the concept and felt comfortable on the subject.

Then, the class went through this newly added and self-design lab experiment for two weeks. Afterwards, a similar survey and a quiz were given during the subsequent lecture to gauge the improvement because of this new lab activity.

The quiz had three questions related to the Specific Heat concept and the associated analysis and calculation. The quiz grade was considered a passing grade if the student could solve two of the three questions. The result of pre/post lab quizzes is illustrated in the following table.

Table 1 Quiz on problem-solving skills improvement related to Specific Heat

number of questions answered correctly	pre-lab	post-lab		
0	4	0		
1	10	2		
2	33	41		
3	8	12		
total	55	55		
average	1.82	2.18	20%	improvement
% passed	75%	96%	29%	improvement

As illustrated in the above table, out of the three questions on the quiz, the class on average was able to solve 1.82 problems after the lecture but before the new lab. This average increased to 2.18 after the lab activity, an improvement of 20%. On the pre-lab quiz, 75% of the students received a passing grade. This means about a quarter of the class did not master the necessary problem-solving skills based on lecture and homework assignment. The passing percentage improved to 96% after the new lab, a remarkable 29% improvement. During the quiz, a simple Likert scale question was also given to gauge student responses:

I have a good understanding of the concept of specific heat.

The student responses are tabulated below.

Table 2 Student responses to the survey question

	Likert scale responses	
	pre-lab	post-lab
A strongly agree	21	33
B agree	24	19
C neutral	10	3
D disagree	0	0
E strongly disagree	0	0
sum	55	55
agree % (A+B)/sum	82%	95%
	improvement	13%

The percentage of students agreeing with the survey statement improved from 82% to 95%, a 13% improvement as the result of the new lab. The pre-lab 82% seemed a little higher compared with the corresponding pre-lab quiz passing rate of 75%. The discrepancy shows some students thought they understood. However, when came to problem solving, they were short. After the new lab, the survey result of 95% is more aligned with the quiz passing grade of 96%.

Impact of the study

By adding a new students designed thermodynamics lab experiment, we accomplished our goal of enhancing student learning on the topic of Specific Heat. The pre and post quizzes showed 20% improvement in student problem-solving skills. The result was also supported by the survey gauging student's perception on their understanding of the topic. Because of the way we conducted the new lab, the impact goes beyond teaching a thermodynamics concept well. For this newly added lab activity, we saw the following impacts:

1. It provided additional evidence of meeting ABET Criterion 3 on Student Outcome #6: an ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering judgment to draw conclusions.

2. It provided a new approach of letting students design their own labs and projects to improve student learning.

3. It created an active learning environment which greatly enhanced the learning outcome and the learning experience.

4. It bridged the discrepancies between the instructor's teaching and the students' understanding, therefore provided a possible new teaching approach to let students design experiments for students to learn difficult STEM concepts.

When discussing a difficult topic in an engineering course, it is largely up to the instructor to find a better way to explain and to connect it to the real-life applications. The instructor could also use videos or demos in the classroom. The return of such effort could be limited. Students were mostly passive participants. The work presented in this paper, and the work by many others, suggested a different approach of letting students design their own labs and projects to improve student learning.

In this approach, many have tried successfully in the past. For example, Smyser [19] found success in letting students design new lab experiments as their Capstone projects for the Internal Combustion Engine course and the Dynamics and Vibration course. The student designed lab and the equipment was being used for the future students. We intend to explore further this approach to address difficult concepts students experienced in the engineering curriculum.

Conclusion and Future Research

A student designed experiment lab class created an active learning opportunity to the students. It was utilized to help the students to learn the concept of Specific Heat in a thermodynamics course. Based on the pre/post quizzes and survey results, the approach improved student learning significantly.

Besides create an active learning environment to improve students' learning, this approach provided additional supporting evident of meeting ABET Criterion 3 on Student Outcome #6: an ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering judgment to draw conclusions.

We intend to continue this work by expanding it to other topics students encountered difficulties in their understanding. We also plan to explore further the ideas of letting students design their own lab as well as projects to improve student learning in various engineering curriculum.

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