
AC 2012-4999: NOVEL APPROACH TO CONDUCTING LABS IN AN INTRODUCTION TO THERMODYNAMICS COURSE

Prof. Teodora Rutar Shuman, Seattle University

Teodora Rutar Shuman is an Associate Professor at Seattle University, Department of Mechanical Engineering. She received a B.S. in mechanical engineering from University of Belgrade, Yugoslavia, and a M.S. and a Ph.D. in mechanical engineering from the University of Washington. She pursues research in electro-mechanical systems for sustainable processing of microalgae. Email: teodora@seattleu.edu.

Dr. Gregory Mason, Seattle University

Novel Approach to Conducting Labs in an Introduction to Thermodynamics Course

Abstract

This paper describes an easily implementable new approach to thermodynamics laboratory instruction that directly addresses ABET Criterion b) *an ability to design and conduct experiments, as well as to analyze and interpret data*. In a traditional lab, students conduct preconfigured experiments based on established procedures. They then gather, analyze and interpret data, and write reports. However, little is done to train engineering graduates to design experiments for a specific purpose and without a prescribed procedure. However, engineering professionals are frequently tasked with designing experiments to demonstrate performance of a device they designed or developed in order to prove a physical phenomenon. Hence, it comes as no surprise that ABET has embraced this criterion for close to a decade.

Introduction to Thermodynamics requires that students learn basic, yet complicated concepts, such as determining properties of pure substances, calculating heat and work exchanged during a process, and the first and second law of thermodynamics, before they can tackle complex applications, such as thermodynamic cycles or combustion systems. These basic concepts are conducive to simple, conceptually oriented laboratory assignments that parallel the classroom instruction. Those laboratory assignments are an ideal place to implement experimental design, because the concepts are still fundamental and intuitive.

We have implemented this approach in our weekly Introduction to Thermodynamics labs. This paper describes three such labs, including the prelab handouts, assignments, and equipment. The paper also summarizes our assessment and evaluation of this approach. The assessment utilizes student surveys taken two times throughout the quarter, lab assignment scores, and scores on all course learning objectives that relate to those labs.

Encouraged by the success of the experimental design approach in the first offering, we offered it again, and the assessment data described herein confirm the positive impact on student learning. The results show that students perceive that labs with experimental design are more useful to their learning and that their learning is indeed deeper than in the traditional setting where students follow prescribed procedures in labs.

Introduction

A successful engineer must be proficient in a variety of areas. This includes an ability to design and implement experimental methods in order to test ideas and designs. This ability is directly addressed in ABET Criterion 3¹ as “*an ability to design and conduct experiments, as well as to analyze and interpret data*.” Engineering curricula often have specific courses which teach experimental methods. While this approach can be used to satisfy the ABET criterion, it tends to isolate experimental design to a single class and focus on the technical aspects of experimental design, such as error propagation, instrument calibration and uncertainty analysis. However,

experimental design also requires creative problem solving. The experimentalist must identify the phenomena to be measured, isolate measurable quantities and decide how the measurements will be made. In an educational setting, this creative side of experimental design can also be used to strengthen a student's understanding of a topic. It requires student to synthesize knowledge they have to create an experiment that will help them discover new knowledge – directly addressing the top levels of Bloom's Taxonomy².

Thermodynamics courses often include laboratory components. Traditionally these are labs where students collect and analyze data using prescribed procedure with a preconfigured experimental apparatus. Such labs help to reinforce ideas, but don't encourage students to creatively think about processes, or how various thermodynamic concepts relate to each other. For example, in a traditional lab, student might be asked to record the voltage and current consumed by a light bulb and compare that to the heat given off by the bulb. In an experimental design lab students would be asked to develop a way to find the efficiency of the bulb. This requires a deeper understanding of the problem. They must determine what type of energy is consumed, how it is measured, how energy is converted in the bulb, the types of energy given off by the bulb and how that energy can be measured.

At Seattle University, we have integrated experimental design into some of our thermodynamic laboratories in order to strengthen students' understanding of fundamental concepts. Our Introduction to Thermodynamics requires that students learn basic, yet complicated concepts, such as determining properties of pure substances, calculating heat and work exchanged during a process, and the first and second law of thermodynamics, before they undertake complex applications, such as thermodynamic cycles or combustion systems. These basic concepts are conducive to simple, conceptually oriented laboratory assignments and are an ideal place to have students design an experiment.

This paper is a continuation of a paper³ presented at the 2011 ASEE conference in the ASEE DELOS division. The new results and material includes course outline by topic, new pre-lab assignment for Lab#2, and new assessment data taken from a second course that implemented experimental design approach into labs.

The remainder of the paper is divided into four sections. *Course Overview* provides an overview of the Introduction to Thermodynamics course where students perform these experiments and sets the context for the experiments. *Description of Three Labs* describes in detail the three thermodynamic experiments in which students must design the experiment. *Assessment Results* compares the performance of three groups of students, one group that followed prescribed laboratory procedures, and two that designed the laboratory experiments. The *Conclusions* are provided at the end of this paper.

Course Overview

The Introduction to Thermodynamic course is a five quarter-credit course, typically taken by junior mechanical engineering students. The course covers the following topics: thermodynamic properties; equations of state; energy transfer by heat, work and mass, including introduction to heat transfer mechanisms; first law of thermodynamics for open and closed systems; second law

of thermodynamics; Carnot Cycle; thermodynamic, overall, isentropic efficiencies, and effectiveness of heat exchangers; refrigeration and heat pump cycles, including absorption and cascade refrigeration, and other advanced cycles; air-conditioning processes of humid air; Reheat Rankine cycle including means to improve its efficiency; Otto and Diesel cycles; Brayton with intercooling, reheating and regeneration; property diagrams, p-v, T-v, T-p, T-s, h-s, p-h, and Psychrometric chart . The course schedule is shown in Table 1 and is divided into ten weeks; each quarter typically contains ten weeks. Each week has 200 minutes of lectures, contents of which are shown in the second column. Seven labs are offered, in weeks 2, 3, 4, 5, 7, 8, and 10. Labs 1-4 require only 60 minutes per team; labs 5 and 6 require 90 minutes; Lab 7 is a two-and-a-half hour tour of HVAC systems used to air-condition medical research laboratories at Fred Hutchinson Cancer Research Center. Special emphasis during the tour is placed on energy conservation measures that were recently implemented at the center.

Table 1. Overview of the Introduction to Thermodynamics course schedule per each week of a quarter class is offered

Week	In-class topics	Labs
1	thermodynamic properties; 0 th Law; energy transfer by heat, work and mass; boundary work	
2	1 st Law for closed systems; thermodynamic efficiency; heat transfer mechanisms	Lab 1 Electromechanical and thermoelectric conversion
3	Property diagrams (T-v, p-v, T-p) and phase-change processes of pure substances; equations of state	Lab 2 Energy Conversion
4	1 st Law for open systems undergoing steady or unsteady-flow processes	Lab 3 Absolute zero
5	Carnot Cycle heat engine, refrigerator and heat pump; Irreversibilities; Entropy generation; 2 nd Law; 3 rd Law; T-s and h-s diagrams; Isentropic Efficiency;	Lab 4 Ideal Gas Law
6	Isentropic processes; ideal refrigeration and heat pump cycles: simple, cascade, multistage, multipurpose, and absorption; p-h diagrams	
7	Air-conditioning processes of humid air: heating, cooling; humidifying, de-humidifying, mixing; Psychrometric Chart	Lab 5 Refrigeration
8	Gas power cycles; Otto, Diesel, Dual cycles;	Lab 6 Air-conditioning
9	Brayton Cycle with intercooling, reheating and regeneration; Tour preparation	
10	Rankine Cycle and means to increase its efficiency; Rankine with reheat; Combined gas-vapor cycles	Lab 7 Tour

Each of the seven labs is preceded by lectures and homework that cover related theoretical concepts. Weekly lab assignments are listed in Table 2. The table indicates whether the students are required to complete a pre-lab assignment prior to the lab, and whether students write a

formal lab report or only complete a homework assignment related to the lab. Of the seven labs, five include some experimental design component. Labs 1-4 include experimental design in situ, while Labs 1 and 5 also require students to design an experiment as part of lab report, but not implement that experiment.

Table 2. Overview of the labs conducted in the Introduction to Thermodynamics course

Name	Pre-Lab	Report (R) or Assignment (A)	Description
Lab 1 Electromechanical and thermoelectric conversion	x	R	Design and implement an experiment during lab session to evaluate the performance of thermoelectric device. Design, but don't implement, an additional experiment as part of the lab report.
Lab 2 Energy Conversion	x	R	Design and implement an experiment during lab session to determine efficiency of an electric light bulb.
Lab 3 Absolute zero	x	A	Design and implement an experiment during lab session to predict value of absolute zero.
Lab 4 Ideal Gas Law		A	Design and implement an experiment during lab session to verify Ideal Gas Law. Then use experiment to collect data.
Lab 5 Refrigeration	x	R	Follow procedure and take measurements on demonstration equipment. Design, but don't implement, an experiment as part of the lab report.
Lab 6 Air-conditioning		A	Follow procedure to take measurements on demonstration equipment.
Lab 7 Tour		A	Tour of Fed Hutchinson Cancer Research Center's HVAC systems and backup diesel generators.

Labs 1-4 were chosen for experimental design because they do not require expensive equipment and address fundamental concepts. Our goal is to have students do experimental design in small groups so that everyone benefits from having to participate in the design and synthesis of the experiment. Labs which rely on expensive and complicated equipment, such as the refrigeration or the HVAC labs are not conducive to experimental design. The refrigeration lab, for example, utilizes a demonstration system built by P. A. Hilton, an older version of the currently available unit⁴. The goal of that lab is to demonstrate how the components of a refrigeration cycle work and interact, as opposed to discovering some fundamental concept in thermodynamics. Discovery of fundamental concepts is more conducive to physical experimental design in this setting.

This paper describes Labs 1, 2, and 3.

Description of Three Labs

The three experimental labs explained here utilize small modular equipment purchased from PASCO⁵ along with standard laboratory equipment, such as power supplies, multimeters, scale and thermometers. PASCO equipment was chosen for its simplicity and low cost.

The three experimental labs consist of the following parts:

Pre-lab: Students are asked to complete a simple pre-lab assignment that prepares them for the theoretical concepts covered in the lab.

In-lab: Students are given items and equipment to design an experiment to demonstrate a proof of concept, or measure properties. They are given more items than they need and they brainstorm in small teams on what to use and how to set up an experiment. The teams propose an approach to the instructor and explain their reasoning. The instructor guides them through theory to help them evaluate their approach. After a few iterations and final approval by the instructor, they build and conduct the experiment. The instructor monitors the data collection and helps students gather quality data. After the experiment, the teams brainstorm the results and consult with the instructor.

Post-lab: Students are required to write a lab report which documents their process and analyzes and discusses the results. Concepts covered in the lab are also covered in homework assignments and exams.

Each of the three labs is designed to take approximately one hour. The instructor is present during the entire lab period to answer student questions and help them brainstorm. Because these labs are open-ended, students occasionally propose experiments which are impractical, or which require equipment not available to them. In those cases, the instructor either helps the students understand the problems with their proposed experiment, or helps them brainstorm alternative experiments which can be done with the provided equipment.

Each lab is described in the following paragraphs.

Lab #1 – Electromechanical and Thermoelectric Conversion

The goal of this lab is to:

- 1) learn and explain the theory behind the Seebeck and Peltier effects, and electromechanical energy conversion in electric motors
- 2) assemble experimental apparatus to demonstrate Seebeck and Peltier effects, using PASCO Thermoelectric converter device
- 3) design and explain an additional experiment on-paper which would measure the conversion efficiency of the PASCO Thermoelectric converter device (this experiment is not conducted because it would involve permanently disassembling the device.)
- 4) explain their procedure and observations in writing

In lectures preceding the lab the instructor covers fundamentals of conservation of energy, energy transfer by heat and work, efficiency, properties of pure substances, and temperature measurement using thermocouples and thermometers. These lectures and related homework help prepare the students for their first lab. Prior to the lab, students are given a short pre-lab assignment, shown in Figure 1 in its entirety, and an in-class oral quiz. The oral quiz is informal and is given during the lab session just before students begin the hands-on portion of the lab. These exercises prepare the students for the theoretical background required to understand the lab. Once the lab begins, the students are given the instructions shown in Figure 2 and provided equipment required to complete the lab.

Equipment used in this lab is shown in Figure 3. The equipment includes a PASCO Thermoelectric converter⁶, cups, hot-water pot, and a power supply with leads. Students in the lab are also given items they don't need to use (not shown in the figure). Those additional items include: volt and amp-meters with leads, a thermometer, a thermocouple, etc.

During the lab, students first inspect the equipment. Then, they choose the equipment to design, assemble, and perform an experiment to demonstrate the Seebeck and Peltier effects. The thermoelectric converter device has two modes of operation, one that works on the basis of Seebeck effect and the other on Peltier effect. The device also contains an electric motor. Students brainstorm about how the device works while designing the experiment. This is only a qualitative lab, so no measurements are expected. The Seebeck effect can be demonstrated by placing the thermoelectric converter legs into two cups, one filled with cold and the other with hot water, and showing that the fan turns. The Peltier effect can be demonstrated by switching the mode of operation on the thermoelectric converter and connecting it to the power supply. When the legs of the converter are placed into two cups, both filled with room temperature water, students will discover that the water temperature changes - gets hotter in one cup and colder in the other. After discovering how to demonstrate both the Seebeck and Peltier effects, the students brainstorm how to conduct an experiment to measure energy conversion efficiency between temperature of one leg of the device and the power delivered to the fan shaft. Since this experiment would require permanently disassembling the device, it is not actually conducted. Instead students are required to write a methodology for conducting the lab in their lab report.

At the conclusion of the lab, students begin writing their lab report. The report is due one week later. The body of the report contains three sections, shown in Figure 4. Students are allowed one report re-write after they receive grades. The purpose of the re-write is to reinforce understanding of the concepts, and hone their report writing skills. Students are provided written feedback on their graded labs.

LAB #1 – Pre-Lab Assignment

In order to prepare for the lab #1, please make sure that you learn the following concepts before the next lab: Seebeck effect, Peltier effect, and electric motors - principles of operation. Obtain your information from textbooks and other peer reviewed publications.

Figure 1. Pre-lab assignment

LAB #1 – Instructions to students in the lab

First, please examine equipment you were given. Then, brainstorm with your lab teammates on how you can use the given equipment to design experiments that demonstrate the Seebeck and the Peltier effects. Present two experimental plans to the professor. If approved, then set up the two experiments. Have them checked by the professor. Once approved, go ahead and run them and gather data.

In the next part of this lab you are tasked to design another experiment, but not to actually conduct it. This time, you are tasked with measuring the efficiency of the system that powers the fan. Brainstorm with your teammates on how you would do it. The following questions can guide you: What data would you want to gather and explain why? What would you measure in order to get the desired data? Which devices would you use to do those measurements? Keep in mind that you would need to modify the supplied equipment to make the required measurements, and that is why you will not actually conduct your experiment.

Figure 2. Instructions for Lab #1

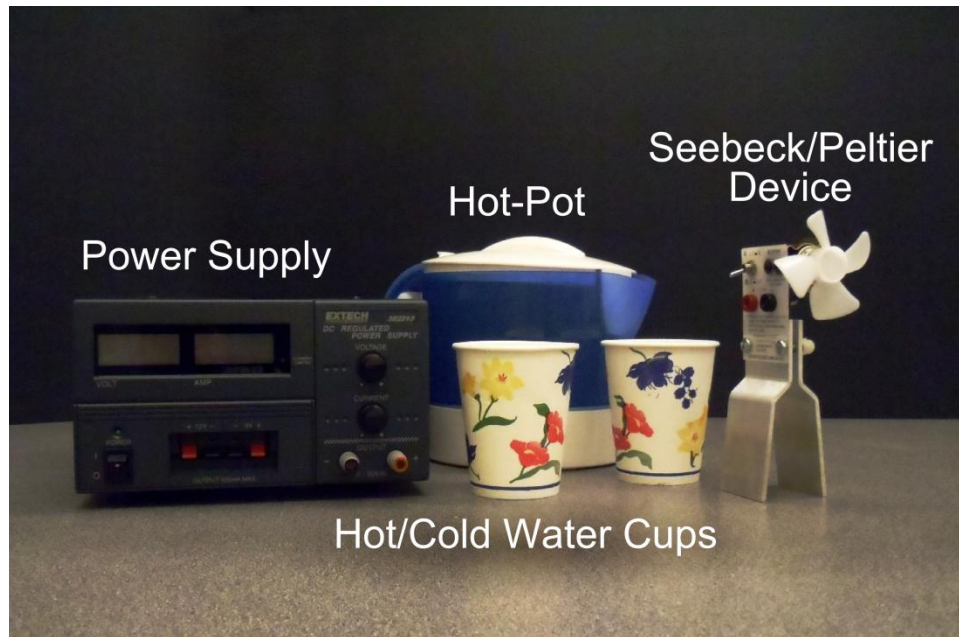


Figure 3. Equipment for Lab #1

LAB #1 – Body of the report

Experiment 1- Methodology and Results

(15 points)

Describe briefly the experiments you conducted to demonstrate the Seebeck effect. Basically, outline the experimental methodology. And, describe what you have observed, i.e., your qualitative results. Please feel free to include sketches along with your text.

Experiment 2- Methodology and Results

(15 points)

Describe briefly the experiments you conducted to demonstrate the Peltier effect. Basically, outline the experimental methodology and describe what you have observed, i.e., your qualitative results. Please feel free to include sketches along with your text.

Design an Experiment

(15 points)

Use sentences accompanied with sketches and equations to explain your methodology for measuring and calculating the overall efficiency of the system that powers the fan.

Figure 4. Content of the body of the report for Lab #1

Lab #2 – Energy Conversion

The goal of this lab is to:

- 1) calculate the efficiency of a light bulb
- 2) learn to apply energy conservation equation to a real thermodynamic system
- 3) assemble experimental apparatus to measure properties necessary to calculate light bulb efficiency
- 4) explain their procedure and observations in writing

In the lectures preceding the lab, the instructor covers conduction, convection and radiation. Prior to the lab, students are given a short pre-lab assignment, shown in Figure 5 in its entirety. Students bring the pre-lab to the lab session where the write-up is reviewed by the professor. Once the lab begins, the students are given the instructions shown in Figure 6 and provided equipment required to complete the lab.

Equipment used in this lab is shown in Figure 7. It includes a transparent jar with built-in 35 Watt incandescent lamp designed to work while submersed in water⁷, a regulated power supply capable of delivering up to 3 A at 12 V, a digital multimeter, stopwatch, thermometer, a scale, and cold water. Students are also given items they don't need to use, such as Styrofoam calorimeters and a bottle of India ink.

At the start of the lab students are encouraged to brainstorm about how to design the experiment. During this time, students grapple with concepts on how to estimate the energy input, output, and losses. Understanding how to estimate the power input usually comes easy. Students typically plan to use the multimeters in series and parallel to estimate direct current and voltage from the power supply, and then calculate power. The next step is to estimate total energy input. Usually, students agree to keep input voltage and current constant, and measure total time. The energy output is harder to grasp. Most students can guess that the energy from the bulb is dissipated in the water, and that the amount of dissipated energy is related to the heat energy input and output. Most expect that the water will warm up, and that they can measure its temperature to estimate

internal energy increase. Few, however, can relate change in internal energy to energy input, dissipated light, and losses from the system, i.e., write the energy conservation equation: $E_{\text{in}} - E_{\text{light}} = U_2 - U_1 + E_{\text{loss}}$. Often the professor must intervene and remind students of the theoretical background. The professor may also need to guide the students while they brainstorm on how to minimize heat loss through the walls, $E_{\text{loss}} \rightarrow 0$. This is important, since students do not yet know how to estimate convection on the outside wall of the device. To minimize loss, PASCO suggests warming the water with the light bulb when water is 10°C below room temperature, T_{initial} , and turning off the power supply and the light at 10°C above room temperature. The temperature of the water will continue to rise until it reaches a maximum value, T_{final} . Change in internal energy is calculated as: $U_2 - U_1 = (m_{\text{water}} + 23 \text{ g (jar equivalent mass)}) \times C_{\text{water}} \times (T_{\text{final}} - T_{\text{initial}})$. The students only measure the mass of water, voltage, current, time, and water temperature.

Following the lab, students are required to write a detailed report. The required contents of the body of the report are shown in Figure 8 below. Students are allowed one re-write after they receive grades. The purpose of the re-write is to reinforce understanding of the concepts, and hone their report writing skills. The better of the two grades is used in the final lab grade.

LAB #2 – Pre-Lab Assignment

In order to prepare for this lab, please write the final form of the energy conservation equation (first law of thermodynamics for closed system) that can be used to calculate the heat loss from the system, Q_{out} [J]. The system sketch is below. Assume that $W_{\text{electric, in}}$ is known. The system is water, and it is closed (no water crosses the boundary.) The water, initially at room temperature, is heated by about 10 K with an electric heater. Assume that thermometer is used to measure water temperature. Then, note how heat leaves the system. Is it through conduction, convection, radiation, or two, or all three modes? That is, explain mode(s) of heat transfer out of the system, Q_{out} . Finally, estimate the efficiency of the heating element as a water heater. Please bring your answers to class neatly typed. Grading will assume the following breakdown:

1. Energy conservation equation (5 points)
2. Heat transfer mode(s) (3 points)
3. Efficiency (2 points)

TOTAL (10 points)

The diagram shows a cylindrical beaker containing blue liquid labeled 'Water'. A red zigzag line representing an electric heater is submerged in the water. Two red wires extend from the heater to a red rectangular box above the beaker labeled 'Electric Heater' with 'W_{in} [J]' written below it. A green thermometer is also submerged in the water, with its label 'Thermometer' written to its right. A black arrow labeled 'Q_{out} [J]' points away from the right side of the beaker, indicating heat loss from the system.

Figure 5. Description of the pre-lab #2

LAB #2 – Instructions to students in the lab

First, discuss your experimental outline with your teammates. Then, devise a team plan and present it to the professor. If approved, then set up the experiment. Before turning anything on, have professor examine your setup. This equipment is delicate, and the following rules must be obeyed:

- Do not fill the water beyond or below the line indicated on the plastic, see-through jar. Filling beyond this level can significantly reduce the life of the lamp,
- Illuminate the lamp only when it is immersed in water,
- Never power the incandescent lamp at a voltage in excess of 13 V.

Once you receive the approval, turn the equipment on and begin taking the data.

Figure 6. Instructions for Lab #2



Figure 7. Equipment for Lab #2

LAB #2 – Body of the report

Methodology

(15 points)

Describe the experimental methodology you undertook to estimate the efficiency of the light-bulb. Describe the experimental setup, the measurements that you have conducted, what you observed. Explain reasons on why you undertook your approach, what actually happened and how that relates to the final task of calculating the light-bulb efficiency. Be very precise and concise.

Data presentation

(15 points)

Present the quantitative data generated. Quantitative data are usually presented using tables. Please label the tables, each measured physical quantity, and units. Present the tables very legibly.

Analysis

Calculate the efficiency of the lamp

(10 points)

Answer the question: is an incandescent lamp more efficient as a light bulb or as a heater? Explain your reasoning

(10 points)

Figure 8. Content of the body of the report for Lab #2

Lab #3 – Experimentally Determine the Absolute Zero

The goal of this lab is to:

- 1) derive the relation between temperature and pressure of ideal gas in a rigid tank; show how that relation changes with the amount of gas, in moles, in the tank; and, what is the value of pressure at absolute zero temperature
- 2) assemble experimental apparatus to experimentally determine the value of absolute zero
- 3) assemble all results in a table and plot results for two different amounts of gas on a single Excel plot, and calculate experimental error

In the lectures preceding the lab, the instructor covers ideal gas law, absolute zero, pressure measurement principles and equipment. Prior to the lab, students are given a short pre-lab assignment, shown in Figure 9 in its entirety. The assignment is submitted at the beginning of the lab and graded during lab. In the beginning of the lab, the students are provided the necessary lab equipment and given the brief oral instructions: “Find the way to use the given equipment to experimentally find the value of absolute zero.”

Equipment used in this lab is shown in Figure 10. It includes a hollow sphere with a pressure transducer tap and a built in thermocouple⁸, a large pail, hot water, ice, a computer with data acquisition software for collecting real time data from a thermocouple and pressure transducer. Students in the lab are also given equipment they do not need, including a volt-meter and a thermometer (not shown in Figure 10).

In this lab, students first inspect the equipment, including the pressure tap and a thermocouple on the rigid sphere, and the computer software interface. They then brainstorm on how to find

absolute zero using the equipment. After their plan is approved by the instructor they connect the equipment to the computer, fill the bottom of the bucket with ice-water, immerse the sphere into it, stir until temperature reading stabilizes, and begin recording data. After the first data-point is recorded, they add hot water to increase the temperature by 10-15°C and record another data-point. They continue heating the water until they have enough data points to see a trend. An alternative approach is to start with almost boiling hot water and add ice to cool it down gradually. The temperature range for the experiment can be as much as 60°C, and the resulting pressure-temperature relationship will still be linear. If the data is extrapolated, students will be able to discover absolute zero at zero pressure. Then, students are asked to change the number of moles of gas in the sphere, repeat the experiment for that new amount of gas, and verify their original estimate for absolute zero.

At the conclusion of the lab, students are required to complete a short assignment in which they display the data in a table, plot both data sets on one graph using spreadsheet software, and calculate experimental error. The instructions for this assignment are shown in Figure 11.

<p>LAB #3 – Pre-Lab Assignment</p> <p>Bring to the lab answers to the following problem:</p> <p>Problem (10 points): Assume a rigid tank filled with air and that the total mass of air is unchanged. Volume of the tank is 1 m³, and it contains 0.1 kg of air.</p> <p>Part a (3 points): Use the Ideal Gas Law (Ideal Gas Equation of State) to find the relation between temperature and pressure in the form: $T = f(p)$, where temperature is in Kelvin [K], and pressure in kilo-Pascal [kPa]. The relation is complete only if you provide the exact values and units of the constants and the dependent and the independent variables.</p> <p>Part b (2 points): What type of a relationship is $T = f(p)$? Is it linear, parabolic, logarithmic or hyperbolic?</p> <p>Part c (2 points): What is the value of pressure at temperature of 0 K?</p> <p>Part d (3 points): If you double the amount of gas in the same rigid tank, what are the answers for Parts a, b, and c?</p> <p>Part a: Part b: Part c:</p>

Figure 9. Description of the pre-lab #3

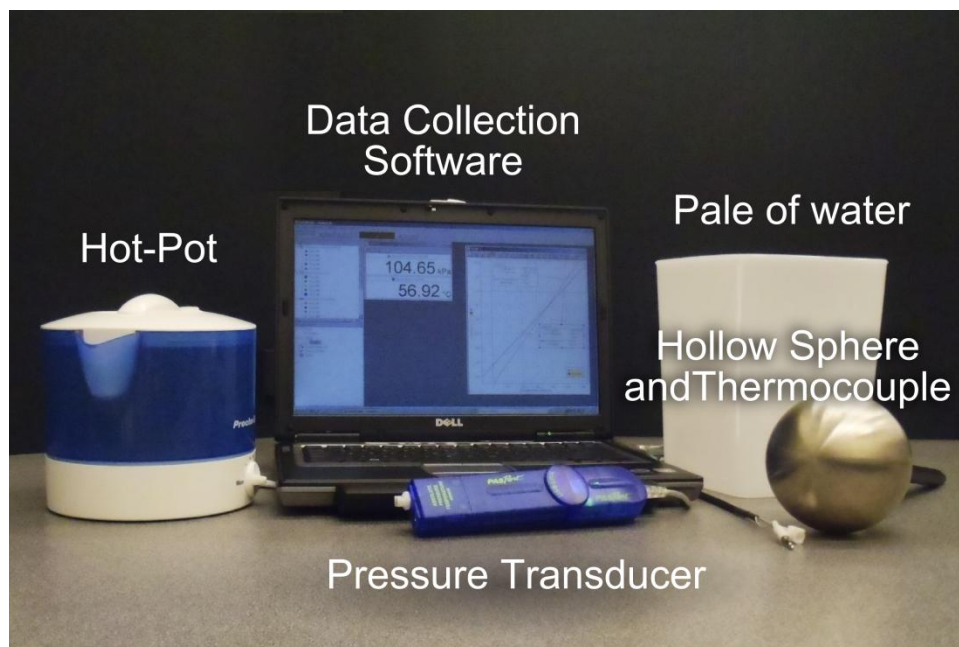


Figure 10. Equipment for Lab #3

LAB #3 –Assignment

Present measured data using a table (10 points). Add appropriate amount of rows and columns. Label all the data with names and units of measure. Place table number and title immediately above the table.

Present both measured data sets on one MS Excel generated graph (10 points). Please make sure that each measured physical quantity shown has a name and a unit. In the graph, please name the axis and include the units, and also include a legend. Legends are necessary when you show two or more datasets. Also, present the experimental error. Place figure number and title immediately below it.

Figure 11. Assignment for Lab #3

Assessment Results

To assess the benefits of incorporating experimental design into the thermodynamics labs, we compared three sets of students. All three sets of students were first term juniors at the time they took thermodynamics, had taken the same prerequisite courses, and took the thermodynamics course from the same instructor using the same text and syllabus. In addition, all three sets of students used the same PASCO equipment and were given similar pre-lab, lab, and report assignments. The first set of students (in 2009 course offering) was given a procedure to follow

during the labs. They were asked to collect and analyze data, but were not required to design the experiment for the lab. The second (2010) and third (2011) sets of students were given an open-ended problem statement and asked to design an experiment, collect and analyze data in order to address the problem statement. We compare the difference in student performance using both indirect (surveys) and direct (graded assignments) measures.

To compare the academic performance of the groups and see if our results could be biased due to one group being “smarter” we looked at the students’ performance in two classes taken after the thermodynamics class. The two classes used for comparison were heat transfer and instrumentation. These two courses were chosen because they are the next two mechanical engineering courses taken by juniors where the courses were taught by the same instructors in both 2009 and 2010. Note that we only compared the 2009 and 2010 groups. The 2011 group had not completed any additional classes at the time of this analysis. The comparison is shown in Table 3.

Table 3. Comparison of Academic Performance of Student Groups

Student Group	Instrumentation	Heat Transfer
<i>without</i> experimental design (2009)	87.3 (std 4.1)	85.4 (std 2.3)
<i>with</i> experimental design (2010)	87.2 (std 5.7)	84.3 (std 5.5)

Based on the student groups performance in these two courses, there is no significant difference in the academic capability of the 2009 and 2010 student groups.

Survey Results

Students were surveyed about the effectiveness of the laboratory assignments at the middle and end of the term. In the middle of the term students were given an anonymous survey. The survey asked the student to rate the usefulness of the labs to their learning on a scale of one to five, with five being the most useful. Figure 12 summarizes the results. The graph suggests that students who did labs with experimental design felt that the labs did a better job of helping them learn the material. This was verified using a Mann-Whitney test on the three populations. The test showed that the three groups are statistically different at a 5% significance level.

Students were also surveyed at the end of the quarter as part of our standardized evaluation of teaching SPOT (Student Perception of Teaching) survey. In that survey students were not asked specifically about the lab, but were asked to comment on the positive and negative aspects of the course. In the group without the experimental design one student commented that the labs were helpful, but several commented that they were not satisfied with the labs. In contrast, several students from the groups that designed experiments commented that the labs were helpful to their learning (see Table 4).

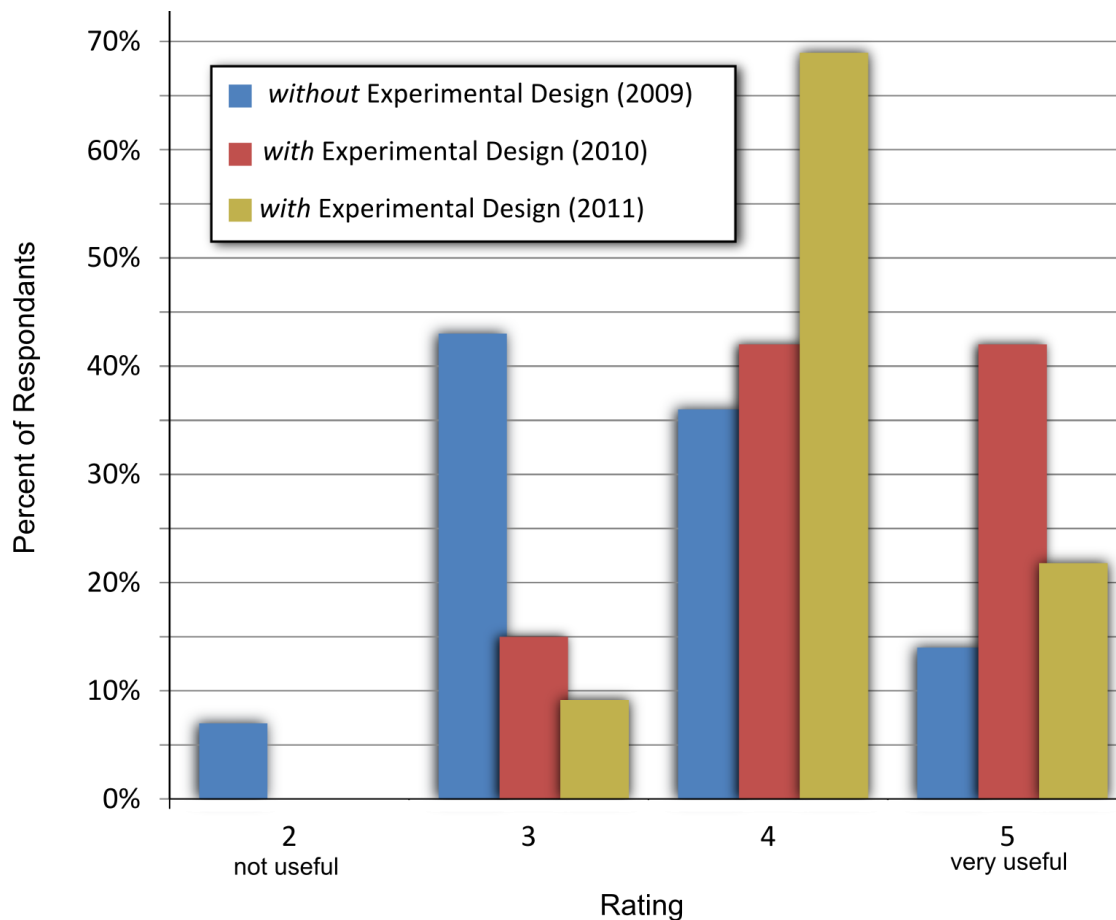


Figure 12. Mid-term survey results on student perception of usefulness of the labs to their learning

Table 4. Summary of student comments

Student Group	Positive Comments	Negative Comments	Respondents
<i>without</i> experimental design (2009)	1	3	17
<i>with</i> experimental design (2010)	3	3	24
<i>with</i> experimental design (2011)	5	2	24

Direct Measurements

We also compared the performance of the three student sets by directly measuring their performance on lab assignments and exam questions. This was done in two ways: 1) comparing lab assignment scores, and 2) comparing student performance on lab-related course objectives as part of the department's ongoing assessment process. First, the lab assignment scores without experimental design were 72 (std 8) and for the two groups with the experimental design they were 91 (std 3) and 87 (std 4). The improved lab assignment scores indicate improved

understanding of the material. This is further evidenced by comparing student performance on exam problems and lab assignments that address course objectives relevant to the material covered in the three labs. Those course objectives, listed in Table 5, were mapped to specific exam questions and lab assignments. (Each course offering had two mid-terms and one final exam.) Average student scores for each of these questions were compared for the three student sets (Table 5). The results show that the student groups which were required to design and implement an experiment performed better on objectives relating to those labs.

Table 5. Average class score on course objectives related to Labs 1-3

Course Objective	Without experimental design 2009	With experimental design 2010	With experimental design 2011
Apply energy conservation equation to solve processes of pure substances in closed thermodynamic systems	76%	85%	87%
Clearly and accurately communicate the purpose, methodology, results, and discuss the results of a thermodynamic experiment in a laboratory report	70%	89%	87%
Design a process to analyze a thermodynamic system	77%	87%	85%
Draw processes of pure substances in T-p, T-v, P-v, T-s, and h-s diagrams with respect to saturation lines	83%	90%	86%
Experimentally test and measure thermodynamic processes in laboratory	70%	90%	87%
Given two independent intensive thermodynamic properties, determine the other state properties of pure substances and atmospheric air	76%	79%	85%
Class Average	75%	87%	86%

Conclusions and Recommendations

This paper presents an easily implementable model that directly addresses the ABET's Criterion b) *an ability to design and conduct experiments, as well as to analyze and interpret data*. The model is applied to the first thermodynamics course (offered early in the junior year) in the mechanical engineering curriculum. The course contains a lecture and a lab component and three labs are explained in detail in this paper.

Our experience shows that simple experiment design can be easily incorporated into labs and without increased time commitment from faculty, as long as it is applied on fundamental

concepts in a simplified setting. We chose to use PASCO labs for their simplicity and low cost. Experimental design has been used for two course offerings. Assessment results show that students perceive that labs with experimental design are more useful to their learning and that their learning is indeed deeper than in the traditional setting where students follow prescribed procedures in labs; thus, validating the merits of this simple model.

References

1. Criteria for Accrediting Engineering Programs, 2010-2011, ABET Engineering Accreditation Commission, <http://www.abet.org/forms.shtml>, accessed January 18, 2011
2. Krathwohl, D. R, Anderson, L. W. *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*, Allyn & Bacon; 2 edition, 2000
3. Rutar, T. and Mason, G., "Design of Experiments in Introduction to Thermodynamics Course." *Proceedings of the 2011 American Society of Engineering Education Annual Conference & Exposition*, 2011
4. P.A. Hilton Refrigeration Unit, <http://www.p-a-hilton.co.uk/R714-Edition-2-GREY.pdf>, accessed on January 17, 2011
5. PASCO Thermodynamics Equipment, <http://www.pasco.com/engineering/thermodynamics/index.cfm>, accessed on January 18, 2011
6. Thermoelectric Converter
http://store.pasco.com/pascostore/showdetl.cfm?&DID=9&Product_ID=1710&Detail=1), accessed on January 18, 2011
7. Light bulb efficiency apparatus
(http://store.pasco.com/pascostore/showdetl.cfm?&DID=9&Product_ID=1644&groupID=476&Detail=1), accessed on January 18, 2011
8. Absolute zero sphere (<http://www.pasco.com/engineering/absolute-zero-sphere.cfm>), accessed on January 18, 2011