Experiments to Accompany a First Engineering Thermodynamics Course

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Abstract

Engineering Thermodynamics is a challenging subject to learn and teach. Often both students and teachers loose sight of the subject's physical motivations and connections. We believe these can and should be brought into courses to enhance learning. To this end, we have developed and use a series of laboratory, computer workshop and field trip exercises for the first semester Engineering Thermodynamics course taken by most Chemical and Mechanical Engineers. These illustrate mass/force/pressure/temperature behavior, work/heat interconversion, energy sources, piston/cylinder action, cooling/heating vapor-compression systems, and easy class visits to university chilled water and steam generation facilities. The activities have been designed to maximize student connections to the physical equipment and processes illustrated in common texts. The talk will summarize the approach, some of the equipment setups, and illustrative exercises given to students for in-class and out-of class work. Our intention is to inform other instructors about options they might adopt and adapt for their own courses.

I. Introduction

Thermodynamics is a discipline that deals with the utilization of energy through application of basic Natural Laws commonly using models for fundamental properties. Its study is basic to science and engineering and it is a core subject in most engineering curricula.

Thermodynamics challenges students in several ways. First, the fundamental principles and procedures which must be mastered for successful application are abstract and mathematical. Next, the devices and systems most commonly treated in the initial engineering course, such as engines, steam power and energy conversion, are unfamiliar and appear complex. In addition, this course is where many students first discover that the required problem solving methods are more sophisticated than memorization and merely doing many example problems.

Interestingly, there are more texts on this subject than virtually any other, but no text has ever been credited with dramatically lowering the frustration factor of teachers or learners. The situation has become exacerbated as students' experience with the real world, such as working with their hands on mechanical and chemical devices, has decreased. While students in years

past usually had some intimate familiarity with Natural behavior and engineered systems, teachers can no longer rely on such background to build connections between book material and engineering reality.

For these reasons, we believe that alternative and innovative teaching/learning activities are needed. To this end, we recently initiated a pedagogy to augment the traditional introductory thermodynamics course in the School of Engineering and Applied Science (SEAS) at the University of Virginia. Our course complemented traditional classroom settings with weekly workshops intended to directly illustrate the principles by hands-on experiments, computer-assisted modeling and study of energy systems, visits to full-scale sites, and team problem-solving activities. We created most of these exercises ourselves since, except for some expensive commercial apparatuses, very few laboratory/workshop exercises presently can be found in the thermodynamics education literature. For example, among the publications and web sites of the several NSF Engineering Coalitions, there are only a few computer-oriented materials and no experiments in this subject.

This paper describes our workshop content, philosophy, and execution. Some activities are discussed in detail and we review part of the assessment information obtained from student evaluations. Finally we discuss our plans for modifications and improvements of experiments for the first engineering thermodynamics course.

II. Some Challenges to Learners and Teachers in the First Thermodynamics Course

As in most schools, our first thermodynamics course follows basic physics and chemistry taken by all undergraduate engineers. It precedes, or sometimes accompanies, courses introducing students to their major discipline, especially in mechanical/aerospace engineering and in chemical engineering. We find that though some of the content such as material conservation, work/energy concepts, chemical reactions, ideal gases, etc. are covered in these courses, students view the treatments in markedly different ways. Unlike the other courses, most students find engineering thermodynamics very difficult and confusing. We suggest there are several reasons for this.

1. *The basic thermodynamics principles are set down in a few general laws <u>first</u>.* From these, the student is expected to master the technique of going from the general to the particular, that is, to understand the general laws well enough to decide which terms do or do not apply to specific problems and to use his or her own judgment to draw system boundaries, establish important and trivial elements, determine strategies for solving and checking, and so on.

In contrast, undergraduate physics texts commonly deal only with “problems” that are well-defined and closely relate to their illustrative examples. Thus, for example, when kinetic energy is presented, the examples and problems use precisely the same kinds of mass/velocity systems. The result is that students solve problems by simply referencing a similar example rather than appreciating the generality of the principles. In engineering thermodynamics the problems generally require the student to do more independent thinking and creating of the relevant elements, equations and approximations. This requires considerably greater

understanding of the fundamental concepts, a major task for most students who have been accustomed to relying on examples and memorization.

2. *Thermodynamics has a bad reputation.* The difficulties encountered by students in the course are transmitted by word-of-mouth so that new students begin a thermodynamics course with preconceptions of difficulty, abstractness, sleepless nights, etc. If teachers do not anticipate such expectations, the natural pedagogy will only reinforce attitudes which strongly inhibit the development of the desired proficiencies.

3. *Student problem solving skills have not been generalized*. At this stage in their development, most students have not recognized the general applicability of problem solving skills. As pointed out by Woods and Crowe[2], they see certain techniques for physics problems, different techniques for chemistry problems, a further set for engineering, and so on. Thus the skills necessary for success in thermodynamics are considered a new "set" rather than useful in all disciplines. When asked why thermodynamics was so hard, a reasonably good student's comment was that the new skills required were all different from what he had learned before and there were so many of them to assimilate.

4. *The material seems unconnected to reality*. Examples used in physics to demonstrate concepts such as a person pushing a wagon or a ball rolling down a hill are common enough that students can connect with them. In thermodynamics, compressors, boilers and isobaric processes have rarely been encountered by students in their daily lives. The opacity of modern technical devices, the decreasing opportunity for young people to work with their hands such as in fixing cars, and their limited skills and interest in observation, make most students unable to fully relate to many of the objects used in thermodynamics. For example, as pointed out by Scott[3], when we use a piston and cylinder to illustrate basic principles of work, most students have never really <u>encountered</u> this simple system, even if they have <u>seen</u> examples in screen door closers, auto trunk and window lift assists, etc.

Our intention has been focused on overcoming the last two difficulties by introducing experimental work along with other activities in our first thermodynamics course.

III. Workshop Objectives

Our two major goals were to bring students in direct contact with some of the simple physical devices used to illustrate concepts in the lecture (such as pistons and cylinders) and to start the "conversation" phase of the learning process[4] when students talk about broad aspects of an observed phenomenon/system so they can identify characteristics and raise questions. Laboratories have always been intended to provide time for students to observe Natural phenomena and to learn how humans might manipulate them. So, for example, it is useful for students to observe water boiling and explore what happens and why. Lectures are intended to have students hear and think about how the principles determine what is actually seen. Our experience is that unless observation and fundamentals are done contemporaneously as complementary aspects of fluid phases and properties of substances, the link between lecture and reality is often too weak to be effective.

Our strategy was to place students in front of "things" and ask them to observe, raise questions, and seek answers from each other. Under the guidance of an instructor/facilitator, using pre- and post-assignments to integrate the experience, the students seem to reach a better position to engage the lecture material. It also provides experience with devices like pistons and cylinders to make the text and lecture line drawings become realities.

IV. Course Organization

The course has two 1¼ hour meetings of the whole class each week. Class sizes range from 40 to 100. In addition, each week there is a set of 1 hour "laboratory" sessions into which the class is divided so that each section has no more than 20 students. These sessions meet in laboratories, computer suites, and plant sites for group activities. In the laboratories, we try to have multiple work stations so that students may actually do some equipment manipulation in groups of 2-4. In such cases, each work station contains a setup. Alternatively, there may be only 1 - 3 setups and either student teams work on each one for a limited time, or the device(s) are demonstrated by the instructor/facilitator (often following instructions solicited from the students). One example setup is shown in Figure 1, a piston/cylinder device mounted vertically on a stand so masses can be placed on the piston and with its length measurable in air and in containers of hot or cold water. We actually have 6 of these setups in the lab so students can work on them all period.

Using the course web site provided by the University of Virginia Toolkit (go to the URL http://www.toolkit.virginia.edu and look for the Materials/Workshops section of the course ENGR 202 for Fall, 1998), the students can obtain about 3 days ahead our preparatory material on the workshop activities and an "Advance Questions" assignment to be answered and submitted upon arriving at the session. We found that the limited time in the lab requires students to have full prior information about the activities, in- and out-of-lab questions and discussion items. Otherwise, they spend most of the time reading and thinking about initial aspects rather than discussing and accomplishing at a concluding level. Giving credit for answering the Advance Questions and indicating the essential information to be obtained in the workshop encourages the students to study ahead.

In the initial part of the course, groups are assigned at random at the beginning of each session and for 4-6 weeks each group is different. Then, when students are used to the rhythm of the workshops and know all members of their section, permanent teams are formed by the instructor. Abilities, personalities and backgrounds are distributed carefully along with matching of teams schedule limitations for group meetings found from surveying the class.

Each assignment is completed on the paper downloaded from the Toolkit, accompanied by any calculational pages, drawings and references. A single paper is submitted by each team within 4 days of the session and unless there is a written report claiming that one or more members have made an inadequate contribution to the effort, all members receive the same score. The

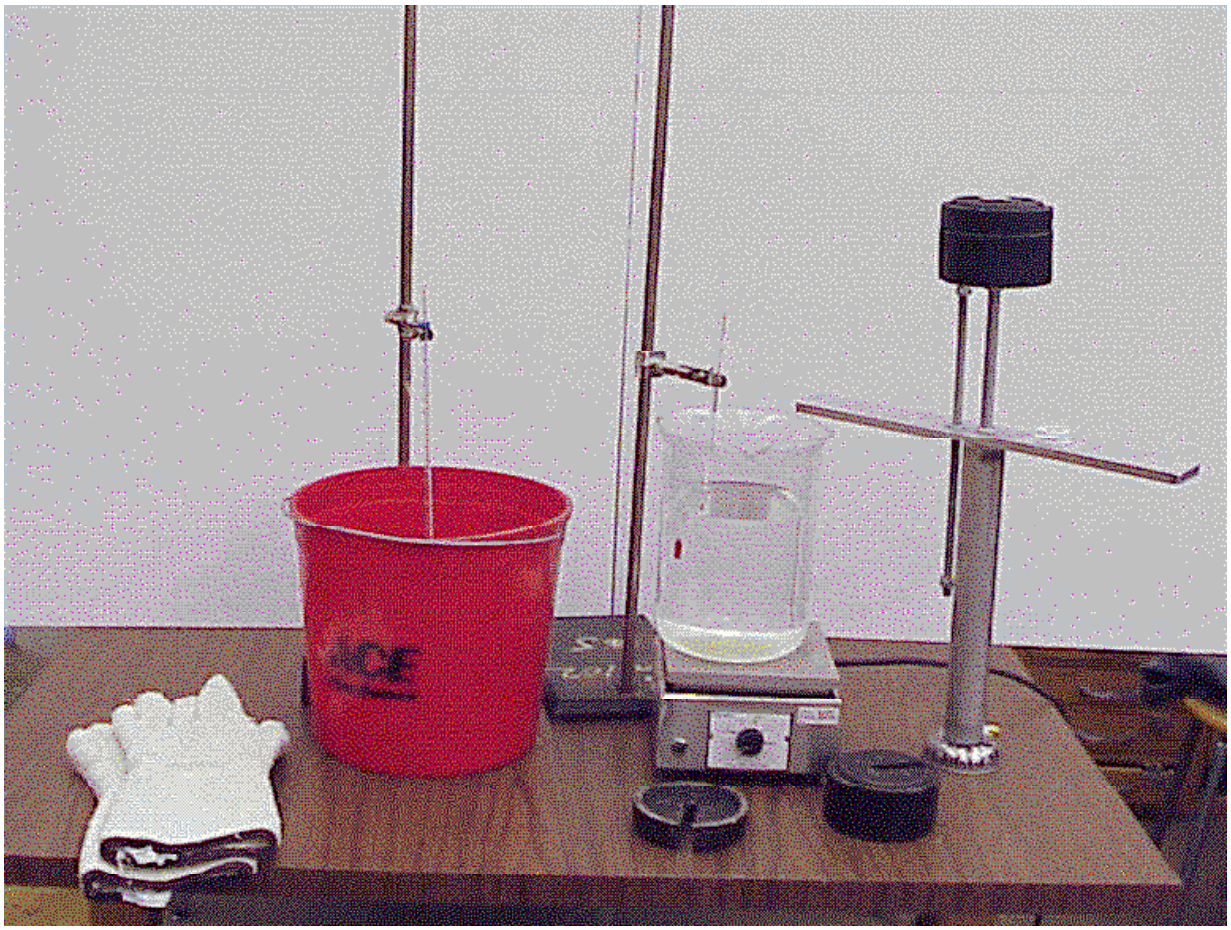

Figure 1. Setup of piston/cylinder equipment for workshops #2 and #4.

follow-up on the workshop material and contemporaneous class subjects is an individually-taken 10-15 minute quiz. Typically, the preparatory material is downloaded on Friday, the workshops are on Monday, the class meets on Tuesday, the Report is due Thursday morning and the Quiz is given in Thursday's afternoon class.

During workshops, teachers and teaching assistants circulate among the student groups to act as facilitators. Though fairly demanding on instructor time and energy, we found this involvement to be critical to this level of student for the following reasons:

1. Each student group possesses varied "manual" skills. Some groups may have great difficulty simply carrying out the physical activities of connecting wires and using a wrench or other simple tool. The facilitators intervene appropriately to prevent these deficiencies from diverting or impeding the students' progress while avoiding merely doing the tasks for the group.

2. Some groups may have no member with the insight necessary to organize the activities, so the facilitator may need to guide the students in planning and executing what they will do. By the third week, we find it adequate to remind the teams to assign roles to their

members - a “leader”, a “reader”, a “recorder”, and in 4-person groups, a “skeptic”.

3. The normal problems associated with group dynamics can prevent even minimal progress. The instructor/facilitator must learn which students will inhibit the process and either anticipate or intervene to force effective group work. This requires close monitoring of the action, especially during the first few lab sessions.

4. Many unexpected learning opportunities arise. Some students notice things that even the instructors did not anticipate and these situations allow reinforcement and guidance. Often these are in response to a suggestive question by the facilitator such as “What did you see?”, “Can you explain what you saw?”, “Have you ever seen anything like that before, such as around the house or out in your car?”, etc. This then can be accompanied by asking one group member to comment on what another one says. While this format can be initially intimidating, when carried out in good humor with positive support of insights, most students will join in and even initiate some of the incisive interaction.

This involvement stimulates and guides the “conversion” phase of learning, taking advantage of its open-endedness and allowing students to avail themselves of many possible discussion paths. In fact we find that no two sessions of workshop day are fully the same when the facilitation is active and positive. When significant “happenings” occur, we also share them in class the next day.

The grading of the workshops, like the homework, advance questions and quizzes, is done by upper division undergraduates using solutions provided by the teachers. We find this to be a satisfactory method of giving credit and feedback and it minimizes expenses while allowing the faculty to focus on creating pedagogy, grading examinations and fostering interactions. The tally of scores, which involves very many elements (as many as 40 different entries per student), is maintained by either a TA or one of the faculty.

V. Workshop Exercises and Their Relation to Class Material

The subjects of the workshop sessions in our recent term are as follows:

#1 SOME ASPECTS OF WORK & HEAT (3 different stations)

A. Equipment: hydraulic jack lifting weights
Measure: mass/force, elevation
Discussion/Analysis: work/potential energy relation, reversibility

B. Equipment: portable-power motorized telescope drive;
Measure power, time
Discussion/Analysis: conversion of 12 volt DC to 120 volt AC efficiency, practical energy capacity, portability issues

C. Equipment: Energy-storage devices (propane tank, battery, compressed air tank, spring, capacitor, water jug)
Discussion/Analysis: suitability of each form for various tasks, environmental issues

#2 SOME MORE ASPECTS OF WORK & HEAT (3 different stations)

A. Equipment: dead weight tester and Bourdon Tube pressure gauge
Measure: mass, gauge P, atmospheric P

Discussion/Analysis: relation of mass/gauge readings, precise meaning of pressure gauge readings

B. Equipment: bicycle wheel generator for electricity to light bulb or resistors in air or insulated water bath

Measure: force, power in, time, water temperature

Discussion/Analysis: conversion of work into other energy forms, efficiencies

C. Equipment: weights on piston confining air inside metal cylinder immersible in hot or ambient water

Observe: changes in piston location

Discussion/Analysis: relationship/transfer of heat and work and behavior of confined low pressure gas

#3 WHIMBEY PAIRS EXERCISE

Pairs (solver/listener) problem-solving exercise, based on Whimbey and Lochhead[5] and developed by Woods[7], using basic thermodynamics problems.

#4 IDEAL GAS CYCLES FOR WORK & HEAT (6 identical stations)

Equipment: piston/cylinder of #2

Measure: T, mass, piston rod length

Discussion/Analysis: pressure/mass calibration, PVT behavior of gas, work/heat calculations

#5 COMPUTER EVALUATION OF WORK/HEAT/ENERGY ASPECTS OF CYCLES OF #4

Spreadsheet computation and graphical analysis of properties (P,T,V,U,H,S) of closed system ideal gas cycles (2 weeks)

#6 DESIGN OF CLOSED SYSTEM CYCLES AS IN #3 FOR SPECIFIED PERFORMANCE

Spreadsheets of #4 used in design mode to determine optimal P, V, T ratios for specified work/heat effects, do “what if” calculations

#7 MULTIPHASE SYSTEMS (2 different setups demonstrated)

A. Equipment: small insulated propane tank that can be vented

Measure: T, mass

Discussion/Analysis: properties of contents at observed states, heat/work effects of venting, utility of propane cans as refrigerators

B. Equipment: Water in flask connected to vacuum pump, immersible in water

Measure: T, P, V

Discussion/Analysis: water properties in states, observe ambient T boiling, consider freeze drying

#8 COMPUTATION OF CYCLES OF MULTIPHASE SYSTEMS

Spreadsheet analysis of Rankine power cycle, vapor compression refrigeration cycles with properties from text computer programs.

#9 FLOW SYSTEMS I. (1 setup demonstrated)

Equipment: Steam supply through expansion valve and tubing into large amount of water

Measure T, P, mass, time

Discussion/Analysis: apply steam tables, mass, energy, entropy balances to obtain water properties, work/heat effects, entropy generation, rationalize piping setup

#10 FLOW SYSTEMS II. (2 setups examined)

Equipment: Refrigerator and air conditioner with covers removed
Measure: several T on air conditioner
Record: parts tagged for identification using schematics & power meters
Discussion/Analysis: similarities/differences of systems, parts necessary for cooling, purpose of other parts, determine refrigerant states, flows, work/heat relations, entropy generation using mass/energy/entropy balances and refrigerant property charts/programs,

#11 University Water Chiller Facility

Equipment: full-scale HVAC water chiller facility
Record: parts tagged for identification using schematics & power meters
Measure: T, P, power on pumps
Discussion/Analysis: similarities/differences of systems in #10, parts necessary for cooling, purpose of other parts, determine refrigerant, states, flows, work/heat relations, entropy generation using mass/energy/entropy balances and refrigerant property charts/programs

#12 THE UVa STEAM PLANT

Equipment: full-scale coal fired boiler plant
Record: parts tagged for identification using schematics & power meters
Measure T, P, flows
Discussion/Analysis: parts necessary for steam production, purpose of other parts, determine flows, energy efficiencies, entropy generation using mass/energy/entropy balances and steam/coal properties

While these form a very full schedule, the students report that the out-of-class work for the lab assignments is less than 3-4 hours/week, though the computer calculation activities are much more time-consuming. We attribute that to the student's limited skill in organizing spreadsheet calculations, especially in using a basic framework for all of the assignments rather than reinventing the structure each time.

VI. EFFECTIVENESS OF THE EXERCISES

At this point, we teachers have seen mixed results from our assessments which include the end-of-semester School of Engineering teaching form and our own custom mid- and end-of-semester questionnaires. Most indicative may be the following observations:

1. Not all students <u>like</u> our laboratory activities and the fraction can change from term to term. Thus, in the last two terms' midsemester assessments, the ratio of the number of students responding that labs were "working well" compared to those saying they were "not working well" was favorable (2:1) and then unfavorable (2:5). This was also reflected in anecdotal comments about the difficulty of getting all team members to meet, producing their assigned contributions, etc. But in this diversity of view, there was an overall positive response. An indicator of this is the responses to the question "How much more 'into the course' were you at the end compared to the beginning?". The ratios of "more" to "unchanged" to "less" were 2:1:1.

We attribute the negative reactions to the following: 1) not all students are desirous of deep technical knowledge, understanding and experience; 2) some remain resistant to any approach which does not fulfill their prior expectations; 3) second-year students often have not reached an intellectual level to benefit from learning situations where the questions do not come directly from "cook-book" directions; and 4) frustration when the quality of the results depends upon attention to detail of measurement, observation and analysis. We do believe there is significant growth to overcome these limitations in our class, but we also find that if students have only one course like ours or no other reinforcement, it becomes an isolated experience whose impact on professional engineering objectives is often minimized.

2. Our attempts to integrate spreadsheet calculations with the labs and class material was generally unsuccessful. Thus, individual comments were mainly directed positively toward the "hands-on" activities and negatively toward the spreadsheet calculations. The mean and standard deviation to the questions "How important were the following to what you learned?" with allowable answers of "Very Important (1), Important (2), Somewhat Important (3), Not Important (4)" were 2.3 ± 0.9 for labs and 2.9 ± 0.9 for computational workshops. The students rated problem solving and lectures as most important (1.6 ± 0.6 and 2.0 ± 0.9) while in-class activities and the text of lesser value (both at 2.6 ± 1.1). While it might be possible that spreadsheets become very unattractive compared to real equipment, we believe that it is more a result of the extra effort, care and attention needed to be successful on the computer.

3. Our faculty colleagues remain skeptical of the value of this effort. When others have been assigned to teach the course, they have not implemented workshops nor even accepted our offers to facilitate. Perhaps faculty, like students, find change from well-defined structure and materials too challenging to take on.

VII. Conclusions

We have developed and use a series of laboratory, computer and field trip exercises for the first semester Engineering Thermodynamics course taken by most Chemical and Mechanical Engineers. These illustrate mass/force/pressure/temperature behavior, work/heat interconversion, energy sources, piston/cylinder action, cooling/heating vapor-compression systems, and easy class visits to university chilled water and steam generation facilities. The activities have been designed to maximize student connections to the physical equipment and processes illustrated in common texts and lecture. We believe that these workshops have made overall positive impacts on the learning of thermodynamics principles and applications by our students.

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