AC 2012-5503: ASSESSMENT OF STUDENT KNOWLEDGE IN AN INTRODUCTORY THERMODYNAMICS COURSE

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Assessment of Student Knowledge in an Introductory Thermodynamics Course

Abstract

The first course in thermodynamics builds the foundation for the thermal science courses in an undergraduate mechanical engineering curriculum. Students who master the fundamental concepts typically do well in the follow up thermal science courses. Therefore, assessment of student knowledge in this course is essential for student success in the follow up courses. Assessment of student knowledge is usually achieved through homework assignments, one or two mid-semester exams, and a final examination. The difficulty is that only simple problems can be included in a fifty-minute exam and not all the topics covered in a course can be covered during exams. Therefore, instructors rely on homework assignments to give students experience of solving more complex problems. However in the recent years many students have access to textbook solution manuals through a variety of sources. It is difficult to convince students that an important part of their engineering education is to learn how to set up and solve problems on their own. As a result, an increasing number of students receive high scores for homework assignments yet do poorly on exams, We have noticed that by increasing the number and frequency of examinations, students gain a deeper understanding of the subject matter. But the increase in the frequency of the examinations requires more work by the instructor in writing and grading examinations. This is especially true for classes having large enrollments. In the last few semesters, we have tried new ways of assigning homework problems and assessing student knowledge in our introductory thermodynamics course. Our experience includes large classes with enrollment exceeding 120 students. This paper describes our experiences in teaching an introductory thermodynamic course and its effect on student learning outcome. Students were surveyed in recent semesters to get their feedback on the methods used in teaching the course and the assessment of student knowledge. This paper provides a summary of the survey results.

Introduction

Mechanical engineering (ME) degree programs in the United States typically require either a single 3 or 4 semester hour (SCH) course or a two-semester course sequence in thermodynamics. The first course focuses on the fundamental concepts and the second course focuses on applying the concepts in the design and analysis of more complex thermodynamic systems. In some degree programs, the second course is not required but is an elective. Our ME program requires a two-semester course sequence in thermodynamics: ME 3293 Thermodynamics I and ME 4293 Thermodynamics II. In the first course students are introduced to such concepts as the thermodynamic systems, extensive properties, intensive properties, various forms of energies, work, heat transfer, conservation of mass and energy, and the second law of thermodynamics. Students are also learn how use from tables, charts, or appropriate equations for evaluating thermodynamic properties. Analysis of simple vapor and gas power, refrigeration, and heat pump cycles are included to demonstrate the application of the fundamental concepts. The second course typically concentrates on the application of fundamental concepts and laws in the analysis of advanced thermodynamic cycles, study of gas mixtures, psychrometric applications, and an introduction to combustion processes. Other topics covered in the second course include exergy, thermodynamics relations, and phase equilibrium.

The first course in thermodynamics builds the foundation for other thermal science courses required in the ME program. Our experiences indicate that those students who have a sound understanding of the fundamental concepts do well in the second course. But those who have a shallow knowledge of the foundational concepts struggle in the follow up courses. In teaching the first course in thermodynamics for several years, it is realized that many students have difficulties in grasping some of the fundamental concepts associated with the course. The range of difficulties include appropriate selection of thermodynamic systems; distinguishing the differences between the extensive and intensive properties, evaluating properties from tables, equations; charts, and or software programs; using the correct equations for the first and second laws of thermodynamics in the analysis of thermodynamic systems; or using appropriate solution techniques in solving problems.

Our focus of teaching the first course in thermodynamics has always been on emphasizing the fundamental concepts. We have tried to make sure students have a full understanding of these concepts, before proceeding to the second course in thermodynamics or other thermal science courses. We have been using homework assignments, at least two mid-semester exams, a design project, and a comprehensive final examination to assess student knowledge in the course. In recent years we have noticed that more students have access to textbook solution manuals through a variety of sources[1]. We have had a difficult time to convince students that an important part of their engineering education is for them to learn how to set up the problem and work to obtain the solution on their own. If homework assignments are selected from the textbook, they grade earned by the student may not be a good indication of their knowledge of the material. As a result homework is less reliable in assessing student knowledge of the topics coursed in the course, and more reliance is place on exams. The difficulty is that only simple problems can be given in time-limited mid-semester exams. The time limitation makes it difficult to assess student knowledge of many topics covered in the course. One option is to increase the number and the frequency of exams given during the semester.

The increase in the frequency of the examinations requires more work by the instructor for writing and grading additional examinations. This is especially true for classes having large enrollments. Our experience includes large classes with enrollment exceeding 120 students. In the last few semesters, we have tried new ways of assigning homework problems and assessing student knowledge in our introductory thermodynamics course offerings. We have increased the number of exams and quizzes given in the course in order to enhance the evaluation of students' knowledge. The following sections describe the actions taken to address the problem of student access to solution manuals and explain the resources used in grading homework assignments and exams. A number of examples of homework problems and projects given in the course for helping students to learn and apply the fundamental concepts are also included in the paper.

Student Access to Solution Manual

Most engineering textbooks provide a large number of excellent problems at the end of each chapter for homework assignments. The publishers also provide solution manuals as a resource for the instructors. Most modern solution manuals provide detailed solutions for each problem in the textbook. In more recent years the textbooks solution manuals are prepared in digital format, which makes it easy for the publishers to deliver them to instructors. This has also made it easier for students to get access to solution manuals. Most engineering textbook solution manuals are now readily available to students through the Internet. We have noticed that each year a larger number of students are using solution manuals in doing their homework assignments. In course surveys conducted recently in several of our courses, over 90 % of responded indicated that solution manuals or similar resources are available that provide solutions to problems in most engineering textbooks.[1] Four out of five respondents (about 80%) stated that they have used solution manuals to help them solve problems in their engineering courses.

The availability of solution manuals has adversely affected student learning. In using solution manuals, students avoid the time and struggle necessary to solve homework problems to gain a deep understanding of the subject. Students who use solution manuals typically develop a shallow understanding of the topics presented in the course. Some students simply copy from the solutions manual in completing their homework assignments. Even those who try to understand the solution steps used in the manual or those who use the manual to check their answers before submitting their assignments, develop little confidence in their work. We have observed that those students who we had a suspicion of using the solution manuals in the first course in thermodynamics often had difficulties in solving problems in the second course sequence.

Table 1 compares the grade distribution in the ME 3293 for semesters prior to wide use of solution manual by students with that for the spring semester 2007 when the instructor suspected that most students were using the solution manual. In Table 1, N represents the number of students. It is evident from the data in the table that the passing rate course sharply decreased when there were indications that a large number of students had access to the textbook solution manual. The ME program at this institution requires that all mathematics, science, and engineering courses be completed with a grade of ‘C” or better. Therefore, the unsuccessful attempt is defined when a student does not complete one of these courses with a passing grade of “A”, “B” or “C” and receives grades of “D,” “F,”or “W” (withdraw). There are several possible explanations for the higher rate of DFW in spring 2007. The lower passing rate might be the result of a small sample size or simply a pool of unmotivated students. For this course the instructor offered recitation sessions, but few students took advantage of attending the recitation sessions or contacting the instructor for help in solving homework assignments. A good probable reason was that many students had access to the solution manual, and did not find it necessary to seek instructor’s help for solving textbook homework assignments. We believe the main reason for poor performance by many students was that they had access to the solution manual. Many students who had perfect scores on the homework assignments could not solve very similar or much simpler problems during the exam. In few cases students were confronted for academic dishonesty. In these cases students admitted that they were using the solution manual or others resources to do their homework.[1]

Similar results in grade distribution have been observed in other courses. Table 2 shows grade distributions for two different semesters of ME 4293 taught by the same instructor in spring semesters 2008 and 2009. In spring 2008 a new edition of the textbook was adopted and the solution manual was not yet available to most students. In spring 2009 a different textbook was used and its solution manual could be accessed through the Internet. Table 2 shows that in spring 2008 when few students had access to the solution manual, the passing rate was higher than the one for spring 2009 when most students were using the solution manual in completing their assignments.

Table 1. Comparison of grade distribution in ME 3293 for semesters when few students had access to the textbook with spring 2007 when most students had access to the solution manual

Grade	Limited Student Access to Solution Manual (N=324)	Large Percentage of Students Using Solution Manual for Assignments (N =40)
A	11%	12%
B	19%	15%
C	21%	5%
ABC	**51%**	**32%**
D	10%	30%
F	20%	10%
W	19%	28%
DFW	**49%**	**68%**

Table 2. Grade distribution comparison of the same course taught by the same instructor in two separate semesters

Grade	Limited Student Access to Solution Manual (N=38)	Large percentage of Students Using Solution Manual for Assignments (N=57)
A	17%	12%
B	31%	10%
C	26%	18%
ABC	74%	40%
D	17%	14%
F	9%	14%
W	0%	32%
DWF	26%	60%

Assessment of Student Knowledge

Student knowledge is evaluated through homework assignments, exams, projects, and pop-quizzes and grades are assigned based on the weight assigned to each item. In the last several semesters the weights assigned to homework assignments have been changed a few times because homework grades are not considered a reliable indicator of student knowledge.

To address the problem of student access to solution manuals and to be fair to students who completed their own homework assignment without the use of solution manual, and reducing the weight of homework scores on the final grade was gradually reduced from 20 % to 5%. However, most instructors believe solving homework problems is essential to to learn thermodynamics. For several semesters penalties were imposed for not putting any effort into solving homework problems. A policy was adopted that a grade of F was assigned if the total points earned for homework assignments fell below 30% of possible points, regardless of student performance in the exams. An automatic grade of D was assigned if the points earned for homework assignments fell between 30% and 40% of possible points and if the students were earning an equivalent grade of D or better in their exams. The policy also rewarded students who completed their homework assignments and performed well in exams. For each exam grade above 70 points, homework grades were doubled for the assignments directly related to that particular exam. This policy showed little or no improvement in student performance, or student behavior for using the solution manuals as every semester more and more students were using solution manuals for their homework assignments.[2]

To reduce the pressure of using the solution manual in completing homework assignments, a revised policy was employed in spring 2010, giving no weight to the homework assignments unless students earned grades of 70 or higher on their exams. This resulted in a large number of students not attempting to solve homework problems, since we provided solutions to assignments after they were collected. This course section was taught by the same instructor as the one teaching the course in spring 2007. Even though the passing rate improved from 32.5% in spring 2007 to 40% in spring 2010, student success rate was still low since either students were not attempting homework assignments or there were still using the solution manual.

In fall semester 2010 a new approach was adopted for assigning and grading homework problems in the second thermodynamics course sequence (ME 4293). Two different sets of homework problems were assigned for each chapter. One set was assigned from textbook which carried no weight on the final grade except for giving students an opportunity to earn bonus points based on their performance in each examination. For each exam grade exceeding 70 points, up to 5 bonus points were awarded based on the number of homework assignment from the textbook attempted and completed. Students were advised at the beginning of the semester that solving textbook homework problems independently is an important part of the learning process and the reason for not awarding any direct points to those problems was to remove any pressure for using the solution manual or similar resources. The second set of homework assignments, called external problems, was developed by the instructor and carried 10 % of the final grade. This policy produced a better result, as the class passing rate increased from 44% in spring 2009 to 61% in fall 2010. Also a much higher percentage of students received grades of A and B (53% in fall 2010 as compared to 29% in spring 2009). There was still a flaw with this policy as a number of students attempted very few problems assigned from the textbook.

In spring semester 2011 the homework grading policy was modified again for the first course in thermodynamics (ME 3293). Again two different sets of homework problems were assigned. One set was assigned from the textbook which carried a weight of 4% on the final grade and other set designed by the instructor (external problems) carried 6% of the final grade. Since the textbook had excellent problems and students benefited greatly if they do those problems independently, up to 5 bonus points (depending on the percentage of points received for the textbook homework assignments) were added to the semester score, if students received an average score of at least 70 for all exams given in the course. With this policy the student attempt in solving textbook problem was improved.

External Problems

External problems were designed for two major purposes. The first was to force student to solve homework problems without the aid of solution manuals. The second was to reinforce fundamental concepts. For this set of homework problems, students were required to start with the most fundamental equations and show all the steps in modifying them for specific applications. This requirement also applied to some problems given in quizzes and exams. For example, for the evaluation of power requirement of a turbine students were required to start with the most general forms of equations for the conservation of mass, the first and second laws of the thermodynamics and simplify them for the turbine. They had to include all the steps required to show whether the changes in entropy during the process were positive, negative or equal to zero.

As stated earlier, the first course in thermodynamics, we emphasize on student understanding of the fundamental concepts. Our homework assignments, quizzes and exams were designed to help students to get a better grasp of the fundamental concepts. The purpose of quizzes and exams were to evaluate student knowledge of the fundamental concepts and their ability to apply them to specific thermodynamic systems. Our experience indicated that many students have difficulties in correctly apply the general equations of conservation of mass, first and second laws of thermodynamics to a thermodynamics system and simplify them for a specific application. In many cases they memorize the resulting equations for specific application and misuse them by applying them to any kind of problems. For example many students apply the equation of the second law of thermodynamics for closed systems and apply it to a problem involving an open system.

In solving homework, quiz, and some exam problems, we required students to start with the most general form of the fundamental equations and modify them for a specific application. For example we required students to show why enthalpy remains constant for a process involving fluid flow in an expansion valve. They also had to show why the value of specific entropy increases during the process. As a minimum, students had to state the logical assumptions that the process is a steady state, it involves no transfer of power, and kinetic energy and potential energy effects are negligible. They also had to show the following steps:

$$\cancel{\frac{dm_{cv}}{dt}} = \dot{m}_i - \dot{m}_e \qquad \text{or} \qquad \dot{m}_i = \dot{m}_e = \dot{m}$$

$$\cancel{\frac{dE_{cv}}{dt}} = \cancel{\dot{Q}_{cv}} - \cancel{\dot{W}_{cv}} + \dot{m}_i\left(h_i + \cancel{\frac{V_i^2}{2}} + \cancel{gz_i}\right) - \dot{m}_e\left(h_e + \cancel{\frac{V_e^2}{2}} + \cancel{gz_e}\right)$$

$$0 = \dot{m}\left(h_i - h_e\right) \qquad \text{or} \qquad h_i = h_e$$

$$\frac{dS_{cv}}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \dot{m}(si - se)) + \dot{\sigma}_{cv}$$

$$\dot{m}(s_i - s_e) + \dot{\sigma}_{cv} = 0 \qquad \text{or} \qquad s_e = s_i + \frac{\dot{\sigma}_{cv}}{\dot{m}}$$

We have noticed that many students write the equation for the first law of thermodynamics correctly for a control volume. However, they start with the second law of thermodynamics for a closed system as demonstrated below.

$$m(s_2 - s_1) = \sum_j \frac{Q_j}{T_j} + \sigma$$

$$s_2 = s_i + \frac{\sigma_{cv}}{m} = s_i + \frac{\dot{\sigma}_{cv}}{\dot{m}}$$

In this case, even though student might get a correct numerical answer to the problem, it is clear that they have applied the wrong equation in solving the problem.

Examples of External Problems

The following two problems were designed to help students gain a better understanding of the behavior of fluids in the compressed liquid region, and behavior of ideal gases. Students could utilize such computer software as IT (Interactive Thermodynamics)[3], EES (Engineering Equation Solver[4], or EXCEL to speed up computations. Both IT and EES are very useful in the evaluation of thermodynamics properties, especially when it is difficult and time consuming to evaluate the properties from the tables.[5] In addition these programs have programming capabilities, are easy to use, and are very useful in solving thermodynamic problems that require iterative processes for finding a solution. Depending on the textbook[6, 7] used in a particular semester, we have integrated either IT or EES into the first course in thermodynamics. For those semesters that neither IT nor EES were included as a package with the textbook [8, 9], we have used EXCEL in our thermodynamic courses.[9.]

<u>Example 1</u>

Consider saturated liquid water at 100 ^oC undergoing an isothermal (constant temperature) compression process. For this process evaluate specific volume (in m^3/kg), specific internal energy (in kJ/kg), enthalpy (in kJ/kg), and entropy (in kJ/kg.K), at pressures of 25, 50, 75, 100, 150, 200, 250, and 300 bar. At each state, evaluate the % deviation of property from the saturated liquid state. For each property plot the results versus temperature. Include the properties on a single graph for all given pressures. Discuss the results and explain what kind of conclusion can be made from the results. IT, or EXCE may be used for this analysis.

In this example students gain a better understanding of why the properties of fluids in the compressed liquid region at a given temperature and pressure could be approximated from the liquid saturation properties following the following relationships [5]:

$$\upsilon(T, p) \cong \upsilon_f(T)$$

$$u(T,p) \cong u_f(T)$$

$$h(T,p) \cong h_f(T) + \upsilon_f(T)[p - p_{sat}(T)]$$

$$s(T,p) \cong s_f(T)$$

Example 2

For superheated water vapor, on a single graph, plot the values of h (in kJ/kg) as a function of temperature, for constant pressures of 1 bar, 0.7 bar, 0.35 bar, and 0.06 bar. What kind of conclusion can be made from the graph that you have constructed? What is the largest value of P_R in this problem? Does water behave as an ideal gas for the range of pressure and temperatures used in the plot? Explain.

By examining the graph, explain why

$$c_p = \left(\frac{\partial h}{\partial T}\right)_p = \frac{dh}{dT}$$

You may use IT or EXCEL for this analysis.

In this example students gain a better understanding of why for the ideal gases h is in a function of temperature only. Also they can understand why the c_p is independent of pressure.[5]

Example 3

Air in a piston–cylinder assembly is compressed from an initial state where T_1 = 300 K and 1.0 bar to a final pressure of 10 bar. Assume that air behaves as an ideal gas and the process is an adiabatic and internally reversible process:

(a) Write down the first and the second laws of thermodynamics for a closed system and simplify them for this problem.
(b) Determine T_2, in K, assuming variable specific heats
(c) The work, in kJ/kg, assuming variable specific heats
(d) Recalculate part (b) and (c) assuming constant specific heats.

Example 4

Consider a control volume with a single inlet and a single outlet. Write down the equations for the conservation of mass, the first law and the second law of thermodynamics and simplify them for a steady state, adiabatic, internally reversible process while ignoring the kinetic and potential energy effects.

Using the fundamental relation: Tds = dh – vdP:

(a) Show that based on the stated condition the power can be expressed as $(\dot{W})_{1\text{-}2} = -\dot{m}\int_1^2 \upsilon\, dp$ and if the fluid is incompressible, the power can be expressed as $(\dot{W})_{1\text{-}2} = -\dot{m}v(p_2 - p_1)$.
(b) If the control volume represents a pump operating under the conditions expressed above, evaluate the power required for 2 kg/s of saturated liquid water at 1 bar entering the pump

and exiting at 10 bar? Also evaluate the power required, if the pump has an isentropic efficiency of 75%.

(c) If the control volume represents a compressor operating under steady state, adiabatic, and reversible, conditions, evaluate the power required for 2 kg/s of saturated vapor water at 1 bar entering the compressor and exiting at 10 bar? Also evaluate power required, if the compressor has an isentropic efficiency of 75%.

(d) Compare the results of part (b) and (c) and explain why the power requirement of the compressor is much larger than that of the pump.

<u>Example 5</u>

Air at 1600 K, 30 bar enters a turbine and exits at a temperature is 830 K. Turbine has an isentropic efficiency of 90%.

(a) Write down the general equations for the conservation of mass, the first law, and the second law of thermodynamics for a control volume having a single inlet and single outlet.

(b) Simplify the equations written in part (a) by assuming that the turbine operates at steady state, undergoing an internally reversible, adiabatic process, while ignoring the kinetic and potential energy effects.

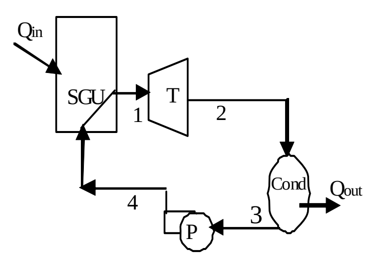
(c) Assuming ideal gas behavior and variable specific heats for the air, determine the pressure at the exit, in bar.

(d) Evaluate the work developed, in kJ per kg of air flowing.

(e) Recalculate parts (c) and (d), assuming constant specific heats (use the values at 300 K).

<u>Example 6</u>

Consider the simple vapor power plant shown in the diagram. The cycle operates at steady state. Steam enters the turbine with a mass flow rate of 1000 kg/s, at 10 MPa and 489 ^{o}C. It expands adiabatically to 36 ^{o}C .and a quality of x_2 =0.77 at the turbine outlet. Saturated liquid water leaves the condenser at 36 ^{o}C. The pressure of water increases isothermally to 10 MPa before it enters the boiler. The pressure changes in the boiler and condenser are negligible. Neglect the effect of kinetic and potential energies for all processes.



1. Show the processes involved in this power plant on P-v and T-v diagrams.
2. Write down the equations for the conservation of mass and the first law of thermodynamics in most general form and simplify them for each process in this cycle.
3. Evaluate the power produced by the turbine and power required by the pump, each in kW.
4. Determine the rates of heat transfer into and out of the cycle, each in kW.
5. Evaluate the thermal efficiency of the cycle.

The following is an example of a project given in the course to help students to get a better understanding of how the properties of ideal gases are evaluated and how the property tables for ideal gases are constructed.

Example of Mini Project:

For an ideal gas

$$P\bar{v} = \bar{R}T, \bar{c}_p(T) = \bar{c}_v(T) - \bar{R}, \bar{c}_v = d\bar{u}/dT, and\ \bar{c}_p = d\bar{h}/dT$$

Start with the fundamental equations:

$$Td\bar{s} = d\bar{u} + Pd\bar{v} \qquad \text{(A)}$$

or

$$Td\bar{s} = d\bar{h} - \bar{v}dP \qquad \text{(B)}$$

(c) Show that for an ideal gas

$$\bar{s}(T_2, \bar{\upsilon}_2) - \bar{s}(T_1, \bar{\upsilon}_1) = \int_1^2 \bar{c}_\upsilon(T)\frac{dT}{T} + \bar{R}\ln\left(\frac{\bar{\upsilon}_2}{\bar{\upsilon}_1}\right) \qquad \text{(C)}$$

Or

$$\bar{s}(T_2, p_2) - \bar{s}(T_1, p_1) = \int_1^2 \bar{c}_p(T)\frac{dT}{T} - \bar{R}\ln\left(\frac{p_2}{p_1}\right) \qquad \text{(D)}$$

(c) Show the results for Eqs (c) and (D), if you also assumed constant specific heats

(c) For an ideal gas assuming isentropic process and constant specific heats, show

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{(k-1)/k} \quad (\mathrm{s}_1 = \mathrm{s}_2, \text{ideal gas, constant } k) \qquad \text{(E)}$$

$$\frac{T_2}{T_1} = \left(\frac{\bar{\upsilon}_1}{\bar{\upsilon}_2}\right)^{(k-1)} \quad (\mathrm{s}_1 = \mathrm{s}_2, \text{ideal gas, constant } k) \qquad \text{(F)}$$

$$\frac{p_2}{p_1} = \left(\frac{\bar{\upsilon}_1}{\bar{\upsilon}_2}\right)^{k} \quad (\mathrm{s}_1 = \mathrm{s}_2, \text{ideal gas, constant } k) \qquad \text{(G)}$$

(d) Given the functional relationship for specific heat of carbon dioxide, CO_2

$$\bar{c}_p(T) = -55.6 + 30.5T^{1/4} - 1.96T^{1/2} \qquad \text{(H)}$$

where, T is in K and $\bar{c}_p(T)$ is in kJ/kmol.K.

Develop a computer routine that evaluates the following thermodynamic properties for CO_2 (You may use IT or EXCEL)

$$\bar{h}(T), \bar{u}(T), \bar{s}^o(T)$$

Let $T_{ref} = 10K, \bar{h}(T_{ref}) = 0, \bar{u}(T_{ref}) = 0, \bar{s}^o(T_{ref}) = 0$

Using your program, generate a table showing properties of CO_2 showing T and the corresponding values for $\bar{h}(T), \bar{u}(T)$, and $\bar{s}^o(T)$

When possible, check the accuracy of your computations, using the data given in the textbook for CO_2.

Submit a report that includes a) formulation of problem for property evaluation; b) program listing; c) program output; and d) brief discussion of results

Exams and Quizzes

For the thermodynamics courses taught by the authors, all quizzes and exams are closed book. We have created an equation sheet that contains the fundamental equations in the textbook and each student is given a copy at the beginning of the semester for all the exams. During exams and quizzes students can only use the equation sheets developed by the instructor and the property tables provided in the appendices of the textbook. Due to student access to the solution manual, we have increased the number of quizzes and exams given in our thermodynamic courses. In ME 3293 taught in fall 2010, there were five mid-terms and a final exam. For the same course offered in spring 2011, ten pop-quizzes, four mid-term exams, and a final exam was given. Considering that the class enrollments were 132 and 124 for the fall 2010 and spring semester 2011, respectively, the assessment of student knowledge requires a large portion of the faculty time.

Using examinations several times during the semester for the assessment of student knowledge in courses with enrollments of exceeding 100 students is not possible, unless other resources are provided and new methods are implemented to assist the instructor in the evaluation process. Prior to spring 2011, a graduate teaching assistant (TA) or a grader was assigned to the course to help the instructor in grading homework assignments (10 -15 hours per week). Prior to this semester, the instructor had always graded the exams. With 124 students in the course, it was realized that it would not be possible for the instructor give multiple exams and quizzes and return them to students in a timely fashion. In spring 2011 a TA and a grader was assigned to the course for a total of 20 hours per week. The grader had taken the second course in thermodynamics with the instructor and was familiar with his grading systems. The authors do not consider that True/False or multiple choice questions alone are appropriate or sufficient for evaluating student knowledge and the ability of students in solving engineering problems. However, it was determined that True/False or multiple choice questions could be used effectively to test student knowledge in knowledge of some of the fundamental concepts. Questions can be designed to evaluate students ability in identify thermodynamic systems (open or closed) or types of properties (intensive or extensive); or determining the phase or phases of a simple fluid from thermodynamic tables. In spring 2011, between 20% and 30% of each exam was based on True/False and multiple choice questions. The remaining portion of the exams required students to solve problems and show solution steps.

The true/false and multiple choice part of the exam were graded electronically in the Office of Testing Services. The instructor provided the solution key for the true/false and multiple choice questions on the exam. In addition to grading homework assignments, the TA and the grader assisted the instructor in grading some of the problems on the exams. The instructor provided a copy of solution with detailed instructions for partial credits for each problem on the exam. The grader, TA, met the instructor in his office to grade each exam. To be consistent in grading, each problem was graded by the same person, and the instructor responded to the questions raised by TA or the grader during the grading periods. All the grading done by the TA and the grader were inspected by the instructor for accuracy. Through this process, all exams were graded on a timely fashion and they were returned to students in the class period following each exam.

The time spent by the instructor in grading exam was the same or less than the time spent in previous semester. For large classes the integrity of the exams is a challenge for the instructors. With a class size of over 100, it is difficult for the instructor to identify all the faces in the class. There are situations when students very seldom attend the class, but show up in the exams. Distribution of exam questions on a timely manor and collection of exam solution pose additional challenges for the instructor. Both TA and the grader assisted the instructor during the exams. All picture IDs, equation sheets, calculators, and the copies of the tables from the textbook appendix were inspected as students entered in the classroom. Also at least two versions of multiple choice questions were used in each test.

The grade distributions for the ME 3293 for the most recent semesters taught by the same instructor are presented in Table 3. It shows that the passing rate has gradually improved from 32.5% in spring 2007 to 48.4% in spring 2010, even though the class size had increased significantly. This suggests that the revised policies in assigning and grading homework assignment gad a positive effect on student success. The policies encouraged students through various means to do their own homework problems without the aid of solution manuals. The other possible contributing factor could have been the results of increased number of exams and quizzes given during the semester, forcing students to study on a more regular basis.

Table 3. Grade distribution for sections of ME 3293 taught by the same instructor.

Grade	Spring 2007 40 Students	Spring 2010 57 Students	Spring 2011 124 Students
A	13%	12%	10%
B	15	11%	15%
C	5	18%	23%
ABC	**32.5**	**40.4%**	**48.4%**
D	30	14%	15%
F	10	14	8%
W	28	32	41%
DFW	**67.5%**	**59.6%**	**51.6%**

In all three semesters, the instructor offered at least one recitation hour per week. At the beginning of the semester a survey was conducted to find a time that the maximum number of students could be accommodated. In spring 2011, because of the large class size, two recitation sessions were offered per week. In these recitation sessions no new materials were covered, but only student questions were answered.

An observation was that the majority of students who took advantage of the recitation sessions were those who did their homework assignments and received good grades in exams. Most students who failed the course submitted few homework assignments and seldom attended the classes, even though attendance was counted as a part of the final grade. It is clear that those students who do not have time or are not willing to put any effort in doing homework or attend lectures would take the advantage of additional services provided for student success. Some of these students only attended the lectures and recitation sessions offered right before each exam. Obviously, these students benefited very little from their last minute efforts.

Student Survey

In spring semester 2011 two surveys were conducted in ME 3293 at the beginning and the end of the semester. Several similar questions related to the time spent in the engineering courses and the use of solution manuals was included in both surveys. Other questions were aimed at seeking students' opinion at the start and the end of semester regarding homework assignments and other topics related to the course.

The results of the student survey are summarized in the following tables. In these tables N represents the number of respondents. Table 4 displays students' opinion regarding the factors that contributes to student learning. The majority of respondents (82%) agreed that 60-100% of learning is based on hearing and seeing lecture materials and doing homework assignments.

Table 4. Results of the survey conducted at the start of the semester regarding the contributing factors to student learning

Q	**Statement**	**N**	**0-20%**	**20-40%**	**40-60%**	**60-80%**	**80-100%**
1	% contribution to student learning based on hearing lecture materials	92	23%	46%	20%	8%	4%
2	% contribution to student learning based on hearing and seeing lecture materials	92	8%	27%	35%	23%	8%
3	% contribution to student learning based on hearing and seeing lecture materials and doing homework problems	92	1%	5%	11%	27%	55%

Table 5 and 6 present the results of student responses at the start and the end of semester, respectively, to the questions related to the amount of time spent in engineering courses. At the start of semester only 29 % of students indicated that they were planning to spend more than 6 hours per week for ME 3293. At the end of semester that number was increased to 39%. At the start of semester 55% students indicated that they would spend less than 4 hours per week outside the classroom preparing for the course.

Results of the survey conducted at the start of the semester regarding solution manuals are summarized in Table 7. The numbers used in the headings are based on the following definitions: 5 = strongly agree, 4 = agree, 3= neutral, 2 = disagree, and 1= strongly disagree. The average value represents the strength of agreements. The results show that most students know that the solution manuals are available for most engineering textbook and they have used the solution manuals for doing their homework in engineering courses. The majority either strongly agreed or agreed that access to solution manuals helps them to learn the material. Only 3% disagreed or strongly disagreed with the statement. Table 8 shows the results of the survey conducted at the end of the semester regarding the scholastic dishonestly. Approximately 42% of the respondents indicated that scholastic dishonestly was a problem in the college.

Table 5. Results of the survey at the start of the semester regarding the weekly time spent for each engineering course

Q	Statement	N	Less than 1 hour	1-2 hours	2-4 hours	4-6 hours	More than 6 hours
1	For each 3 semester credit hour engineering courses that you have taken in the past, on the average, how many hours did you spend studying and doing homework per week	92	1%	17%	37%	24%	21%
2	How many hours per week are you planning to spend for studying and doing homework for this course?	92	0%	8%	23%	40%	29%

Table 6. Results of the survey conducted at the end of the semester regarding the weekly time spent for each engineering course

Q	Statement	N	Less than 1 hour	1-3 hours	4-6 hours	7-9 hours	More than 9 hours
1	On average, how many hours per week do you spend studying for a typical engineering class.	71	0	26%	36%	24%	14%
2	How many hours per week did you spend studying for this class?	71	1%	19%	41%	26%	13%

Table 9 shows the results of the survey conducted at the start of semester regarding and the importance of homework assignments in the learning process. The majority of the respondents agreed that the solutions to the example problems in the textbook and solving homework assignments are important factors for them to learn the course materials. Table 10 displays the results of the student responses to the question on the factors that made it difficult for them to complete their homework assignments. The following factors were identified by many students for not doing their homework: ‘homework problems are tedious and time consuming,” ‘too many homework problems assigned,” and “do not have time due to other commitments” received the higher votes by the respondents. In Table 11 more than 90% of students agreed that students should attend lectures, complete their homework assignments, and study on a regular basis in order to do well in the course. Table 12 shows the results of the survey conducted at the end of the semester on the factors that made it difficult for students to attend lectures.

Table 7. Results of the survey conducted at the start of the semester regarding solution manuals. 5 = strongly agree, 4 = agree, 3= neutral, 2 = disagree, and 1= strongly disagree

Q	Statement	N	5	4	3	2	1	Ave
1	Copies of solution manuals for most engineering textbooks are readily available to students.	92	8%	34%	52%	5%	1%	3.4
2	There are resources other than the solution manuals that provide solution to engineering textbooks problems.	92	11%	40%	46%	3%	0%	3.6
3	You have used solution manuals in other engineering courses.	92	14%	49%	14%	16%	7%	3.5
4	You are planning to use solution manual to do your homework for this class.	91	2%	12%	48%	26%	11%	2.7
5	Access to the solution manual helps you learn the material.	92	37%	35%	25%	2%	1%	4.0
6	When solution manuals are available, it is difficult to avoid using them.	92	5%	21%	21%	46%	8%	2.7
7	Getting a high grade by any means is more important than learning the materials.	92	4%	2%	7%	48%	39%	1.8
8	Using solution manuals in completing homework assignments has the same learning benefit as solving problems independently.	92	9%	9%	36%	27%	20%	2.6
9	Using solution manual in completing homework assignments provides the same educational experience as solving the examples in the textbook.	92	9%	23%	33%	23%	13%	2.9

Table 8. Results of the survey conducted at the end of the semester regarding scholastic dishonesty. 5 = strongly agree, 4 = agree, 3= neutral, 2 = disagree, and 1= strongly disagree

Q	Statement	N	5	4	3	2	1	Ave
1	Overall, scholastic dishonesty is a problem in engineering at UTSA.	71	10%	32%	27%	21%	10%	3.1
2	You have cheated on homework in this class this semester.	70	1%	4%	11%	20%	63%	1.6
3	You have cheated on an exam in this class this semester.	71	0	1%	3%	8%	87%	1.2

Table 9. Results of the survey conducted at the start of the semester related to problem solution. 5 = strongly agree, 4 = agree, 3= neutral, 2 = disagree, and 1= strongly disagree

Q	Statement	N	5	4	3	2	1	Ave
1	Solved textbook example problems help you understand the material.	91	49%	36%	11%	1%	2%	4.3
2	The main purpose of homework assignments is to give you an educational experience to solve problems independently.	92	50%	42%	7%	1%	0%	4.4
3	Solving homework problems is essential for learning the materials and succeeding in this course.	92	60%	35%	5%	0%	0%	4.5
4	You will attempt to solve homework assignments regardless of whether it counts for the final grade or not.	92	52%	38%	10%	0%	0%	4.4

Table 10. Results of the survey conducted at the end of the semester regarding student difficulties in completing homework assignments. 5 = strongly agree, 4 = agree, 3= neutral, 2 = disagree, and 1= strongly disagree

Q	**What made it difficult to complete all of the homework assignments**:	N	5	4	3	2	1	Ave
1	homework problems are tedious and time-consuming	71	28%	46%	13%	8%	4%	3.9
2	too many homework problems were assigned	71	30%	23%	21%	21%	6%	3.5
3	do not have time due to other commitments (work, other courses. etc.)	71	17%	42%	17%	17%	7%	3.5
4	homework problems due before theory covered in lectures	71	18%	21%	27%	25%	8%	3.2
5	homework problems are too difficult	71	6%	28%	28%	30	8%	2.9
6	homework grade isn't a significant part of overall class grade	71	11%	21%	24%	25%	18%	2.8
7	instructor's homework policy	71	6%	14%	41%	27%	13%	2.7
8	don't have way to check if solutions are correct before turning it in	71	7%	21%	24%	34%	14%	2.7
9	repeating this course and have completed similar homework problems	71	6%	3%	23%	24%	45%	2.0
10	do not believe homework contributes to my learning (is not helpful)	71	0%	1%	8%	27%	63%	1.5
11	none of the above, you have completed the homework	69	20%	20%	33%	17%	9%	3.3

Table 11. Results of the survey conducted at the end of the semester regarding the factor contributing to student success in the course. 5 = strongly agree, 4 = agree, 3= neutral, 2 = disagree, and 1= strongly disagree

Q	**In order to do well in this class, students should**	**N**	**5**	**4**	**3**	**2**	**1**	**Ave**
1	attend lectures to understand applications	71	85%	14%	1%	0	0	4.8
2	do the homework	71	79%	17%	1%	3%	0	4.7
3	attend lectures to understand the theory	71	75%	20%	4%	1%	0	4.7
4	study on a regular basis	71	56%	37%	6%	1%	0	4.5
4	read the textbook to understand applications	71	62%	24%	10%	3%	1%	4.4
5	read the textbook to understand the theory	71	58%	24%	15%	1%	1%	4.4
6	attend problem-solving recitations held by TA or instructor	70	37%	39%	19%	4%	1%	4.1
7	visit the instructor during office hours	71	24%	38%	28%	8%	1%	3.7
8	get in a study-group with other students	71	28%	31%	27%	7%	7%	3.7
9	use course-specific software tools (IT-Interactive Thermodynamics)	71	30%	31%	17%	13%	10%	3.6
10	study primarily before exams	71	31%	21%	27%	11%	10%	3.5
11	use general software tools (Excel, MATLAB, etc.)	71	8%	37%	34%	11%	10%	3.2
12	get access to a solutions manual	71	4%	24%	37%	18%	17%	2.8

Table 12. Results of the survey conducted at the end of the semester regarding student difficulties in attending the lectures. 5 = strongly agree, 4 = agree, 3= neutral, 2 = disagree, and 1= strongly disagree

Q	**What made it difficult to attend all of the lectures:**	**N**	**5**	**4**	**3**	**2**	**1**	**Ave**
1	traffic and/or parking	62	10%	16%	18%	26%	31%	2.5
2	needed to work on stuff for other classes	62	6%	15%	18%	34%	27%	2.4
3	needed to work (to pay tuition/bills/etc.)	62	11%	13%	8%	35%	32%	2.4
4	normally sleep at that time	61	5%	7%	13%	30%	46%	2.0
5	attending lectures isn't a significant part of overall class grade	62	3%	6%	11%	31%	48%	1.9
6	repeating this course and have heard similar lectures	62	3%	6%	13%	21%	56%	1.8
7	do not believe lectures contribute to my learning	62	2%	3%	8%	31%	56%	1.6
8	none of the above, you have attended lectures	71	56%	24%	13%	4%	3%	4.3

Table 13 shows the results of the survey conducted at the end of semester regarding the external problems. Ninety five percent (95%) of respondents agreed that the external problems were challenging; 90% agreed that by requiring them to start with the most general form of fundamental equations and simplify them for specific application gave them a better understanding of thermodynamics, and 84% of the respondents agreed that the external problems helped them to prepare for exams. The results of the survey summarized in Table 14 shows that 55% of students indicated that they have passed some of their engineering courses without learning much. This confirms that a passing grade does not necessarily signify student success.

Table 13. Results of the survey conducted at the end of the semester regarding external problems. 5 = strongly agree, 4 = agree, 3= neutral, 2 = disagree, and 1= strongly disagree

Q	**Statement**	**N**	**5**	**4**	**3**	**2**	**1**	**Ave**
1	The external problems were challenging.	71	58%	37%	4%	1	0	4.5
2	By requiring you to write the most general fundamental equations (1st law, 2nd law, etc.) and simplifying them for specific applications, the external problems gave you a better understanding of thermodynamics	71	56%	34%	6%	3%	1%	4.4
3	Completing external homework assignments prepared you for the exams.	71	52%	32%	8%	4%	3%	4.3

Table 14. Results of the survey conducted at the end of the semester regarding other courses. 5 = strongly agree, 4 = agree, 3= neutral, 2 = disagree, and 1= strongly disagree

Q	**Statement**	**N**	**5**	**4**	**3**	**2**	**1**	**Ave**
1	You have recently taken engineering classes where you pass the class, yet learned little.	71	18%	37%	14%	25%	6%	3.4
2	This class is harder than other engineering classes.	71	32%	34%	21%	11%	1%	3.8

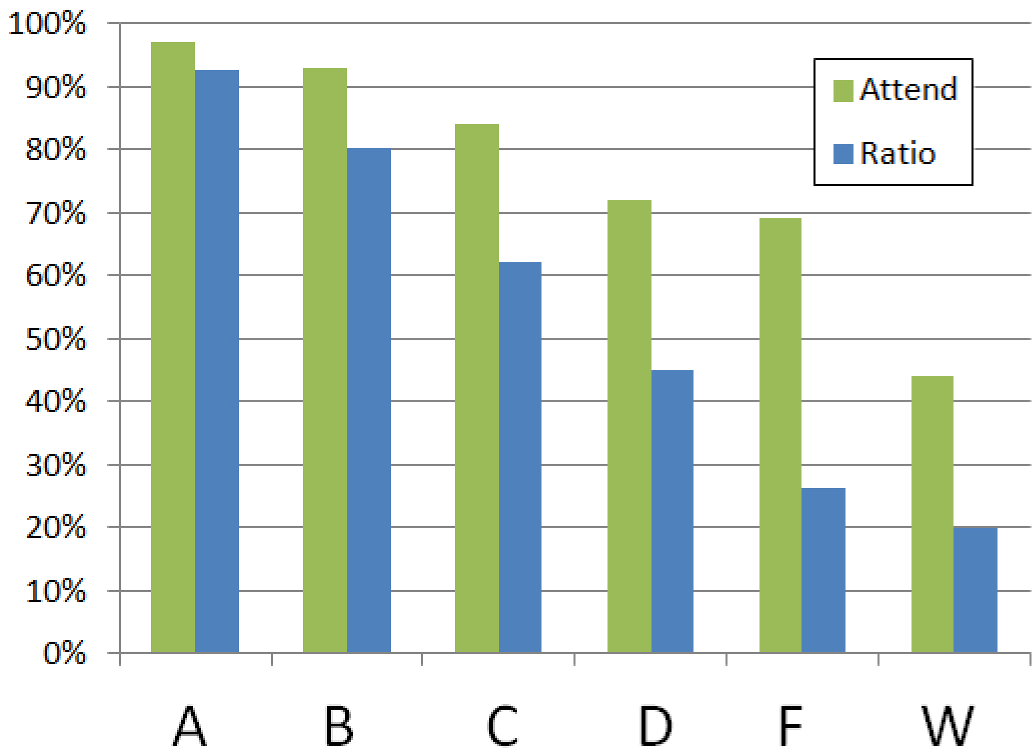
Factors Contributing to Unsuccessful Attempts in Courses

Table 15 shows grade distribution in ME 3293 offered in Spring Semester 2011. The average attendance, average textbook homework scores, and average external homework problem homework grades for each grade category is included in the table. The table shows that the final grade is heavily dependent on student effort in completing homework assignments and class attendance. The instructor teaching method can also contribute to this factor. However, we believe instructors can affect the grades positively, but that is only possible if students are willing to put adequate effort in the course.

Figure 1 shows the data in Table 15 in another way. The attendance data shows that those earning high grades attended class regularly. Those earning an A grade attended more regularly that those earning a B, who were more regular than C. This trend is expected. Also in Figure 1 is the ratio of homework grades. This ratio is the grades from the external problems to the textbook problems. In all cases, the grades from the external problems are less than for the textbook problems, and the same trend is observed. Those earning high grades had a higher "ratio" of homework grades than those earning low grades. This data indicates that ratio was even more highly correlated to the class grade than attendance.

Table 15. Grade distribution in ME 3293, spring 2011

Grade	Textbook assignments	External problems	Attendance
A	81%	75%	97%
B	61%	49%	93%
C	45%	28%	84%
D	31%	14%	72%
F	19%	5%	69%
W	15%	3%	44%



Conclusions

This study investigates the challenges of assessing student competence in an introductory thermodynamics course, and the following conclusions are summarized.

A persistent challenge for instructors is the availability of solutions manuals and their use by students to complete homework assignments. The homework grade is less reliable as an indicator of learning. To assess student knowledge, instructors continue to rely on time-limited examination grades.

One mechanism to counteract the widespread availability of solutions manuals is for the instructor to generate a set of unique homework problems. Grades on these "external" problems are lower than on end-of-chapter textbook problems. The ratio of external to textbook homework problems shows a strong correlation with final course grade.

When confronted with large class size, instructors should consider using multiple-choice quizzes because of the decreased time burden placed on the instructor. However, multiple choice questions should not replace open-ended problem solving questions which are recommended to remain the dominant means to assess student knowledge on exams.

Overall, there appears to be a trend that more students are becoming overly reliant on solutions manuals that are not intended for student use. As such, more students have a false sense of their mastery of the material. It appears students learn best by the difficult and often unpleasant task of struggling to solve open-ended homework problems, as reflected by higher course grades.

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