Challenges in Teaching an Introductory Graduate Level Course in Thermodynamics

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Abstract

Teaching an introductory graduate level course in thermodynamics can be a challenge due to unequal students' undergraduate educational background in thermodynamics. Many of students accepted into a mechanical engineering graduate programs have received their undergraduate degrees from various institutions in the United States or from universities in other countries. The semester credit hours required in thermodynamics for an undergraduate mechanical engineering degree varies among institutions. Some degree programs require only three semester credit hour of thermodynamics; few require a four hour course, while others require a two semester course sequence in thermodynamics, totaling six credit hours. In addition, some mechanical engineering graduate students have received their undergraduate degrees in disciplines other than mechanical engineering, such as civil, aerospace, physics, or chemical engineering. Teaching a course in advanced thermodynamics to students with very diverse background is a challenge. A survey is conducted at the start of semester to gauge students' perception of their knowledge in thermodynamics. The survey is followed by a quiz to assess students' actual knowledge of the fundamental concepts in thermodynamics. Based on the survey and the quiz results, the lectures are carefully adjusted to help students with weaker background to catch up without making students with stronger background getting board. Selection of a suitable textbook for the course is also another challenge. This paper describes the challenges faced in teaching an introductory graduate course in thermodynamics, and how these challenges are addressed. Examples of homework problems, exam problems, and a project assignment are included.

Introduction

Most courses taught at the graduate level, typically require one or more undergraduate courses as prerequisites. For example, introductory graduate courses in fluid mechanics, heat transfer, or mechanical behavior of materials, require similar undergraduate courses as prerequisites. However, it is typical that many of the students entering mechanical engineering (ME) graduate programs either have received their undergraduate degrees from various universities within the United States or from institutions in other countries. Therefore, it is possible that the background preparation and knowledge might not be the same for all students enrolled in a graduate courses. The differences in students' background knowledge are particularly more pronounced in a graduate level course in thermodynamics. In the United States and other countries, the semester credit hours (SCH) required in thermodynamics for an undergraduate degree in mechanical engineering varies among institutions. Some degree programs require only three SCH; a few require a four hour course; while others require a two semester course sequence in thermodynamics, totaling six SCH. The differences in credit hour requirements in undergraduate thermodynamics effect the number of topics or the depth in which topics are covered. In addition, some ME graduate students have received their undergraduate degrees in disciplines other than mechanical engineering, such as aerospace engineering, chemical engineering, general engineering, or physics. The focus of the topic coverage and their applications in undergraduate thermodynamics courses in chemical engineering or physics are different from those in courses offered in ME undergraduate programs. Those students who have taken only a three SCH course in thermodynamics, typically, are introduced only to topics that include thermodynamics system, property evaluation, first law and second law of thermodynamics and their applications. Also, they might have been briefly exposed to such topics as thermodynamic cycles, chemical reactions, and psychrometric analysis. In a six SCH two-semester course sequence in thermodynamics, more time is spend on such fundamentals concepts as: various types of thermodynamic systems, types of thermodynamic properties, evaluation of thermodynamic properties, first law and second law as applied to closed systems and control volumes. Other topics covered in detail in a two-semester course sequence may include complex power and refrigeration cycles, exergy analysis, thermodynamics relations, chemical reaction and combustion, properties of mixtures, psychrometric analysis, introduction to compressible flow through nozzles and diffusers, as well as chemical and phase equilibrium. Teaching an introductory thermodynamics graduate level course can be a challenge due to students' unbalanced undergraduate educational preparation in thermodynamics. Selection of a suitable textbook is also another challenge. This paper describes the challenges faced in teaching a graduate course in thermodynamics and the approaches taken to address the challenges.

An introductory course in Advanced Thermodynamics has been offered in the mechanical engineering graduate program at the University of Texas at San Antonio (UTSA) since 1990. The author was the original instructor who taught the course for the first time in 1990 and has been teaching the course periodically ever since. He has been teaching the course four out of the last five times that the course has been offered in the recent years. He is currently teaching the course again in spring 2017. In the recent years the course has been offered once a year in the spring semesters.

The undergraduate ME degree program in this institution requires a two course sequence in thermodynamics. But, due to the differences in the number of SCH required in thermodynamics in undergraduate degree programs at other institutions, only the first course in thermodynamics was listed as a prerequisite for Advanced Thermodynamics when it was originally offered. In 2010, the graduate program decided not to list any undergraduate courses as prerequisites for the graduate courses. Instead only "graduate standing or the consent of instructor" were listed in the graduate catalog as prerequisites. The rational for listing only "graduate standing" as a prerequisite was that the graduate admission committee would admit only those students into the graduate program that have adequate background in mechanical engineering. However, due to rotation of faculty members in the graduate admission committee, some students were being admitted to the graduate program without adequate background to take graduate courses. Therefore, it became possible for any graduate student, having any or no background in thermodynamics to register for Advanced Thermodynamics. This practice was continued until 2015. Starting in 2016, an undergraduate course in thermodynamics is being required as prerequisite for the Advanced Thermodynamics course. In addition to graduate students, ME senior level undergraduate students with high grade point averages are allowed to enroll in the course with the consent of instructor.

Previous studies have shown that a good understanding of topics covered in prerequisite courses, is essential for students to become successful in engineering courses.[1-3] This is especially true in more advanced courses in thermodynamics. Thermodynamics is perhaps the most highly structured subjects among all engineering courses. It is based on a number of definitions and basic concepts, such as the definitions of open or closed systems, and the understanding of the differences between intensive and extensive properties. Any new topic in thermodynamics continuously builds on knowledge gained in previous topics. Students who lack the understanding of the basic concepts will have difficulty grasping new materials as more advanced topics are introduced in thermodynamics.

When the author began teaching the Advanced Thermodynamics again is the spring semester 2012, it was realized that there were major differences in background knowledge of thermodynamics among students who were enrolled in the course. Few students had not taken any undergraduate course in thermodynamics; some had completed an undergraduate thermodynamics course in disciplines other than ME; few had completed a single undergraduate ME thermodynamics, and others had completed a two-semester course in undergraduate thermodynamics. To gauge students' background in thermodynamics, in spring 2012 the instructor began conducting a survey at the start of semester. The survey questionnaire was divided in two parts. In the first part of the survey, questions were asked about students' undergraduate degree and in the second part questions were asked about students' perception of their knowledge of the topics covered in a two-semester course sequence offered at UTSA.

The first part of the survey asked the following questions:

- Please circle the appropriate answers
    - I am: (a) undergraduate student (b) MS student (c) PhD student
    - My undergraduate degree was/is in: (a) mechanical engineering (b) Other degree (specify) _______________
    - As an undergraduate student I took (a) no (b) one or (c) two thermodynamic courses.
    - If a graduate student, I received my undergraduate degree at (a) UTSA (b) Other institution (specify) ___________________________

A total of 69 students completed the Advanced Thermodynamics course with the author from spring 2012 through spring 2016. Among these students, three (6) were undergraduate-senior, ME students; 51 were pursuing MS degrees, and 12 were PhD students. Of the 63 graduate students, 47 had completed an undergraduate degree in ME and 16 had completed other types of undergraduate degrees that included civil engineering, aerospace engineering, chemical engineering, general engineering, engineering science, and physics. Of the 63 graduate students 11 received their undergraduate degrees from UTSA, 18 received degrees from other institutions in the United States, and 34 were international students who received their degrees from institutions in other countries, mostly from India and China. Figure 1 shows the diversity of student background in thermodynamics. Of the 69 students, 40 had completed a two course sequence in undergraduate thermodynamics, 25 had completed a single course in undergraduate thermodynamics, and 4 had never taken a course in thermodynamics. Some of those who had completed a single course in thermodynamics, the course was taken in a discipline other than ME. Those who had never taken a thermodynamic course before had the greatest difficulty with the materials covered in the Advanced Thermodynamics course. In general, those who had taken thermodynamic courses in aerospace, chemical engineering, and physics also had a difficult time in Advanced Thermodynamics.

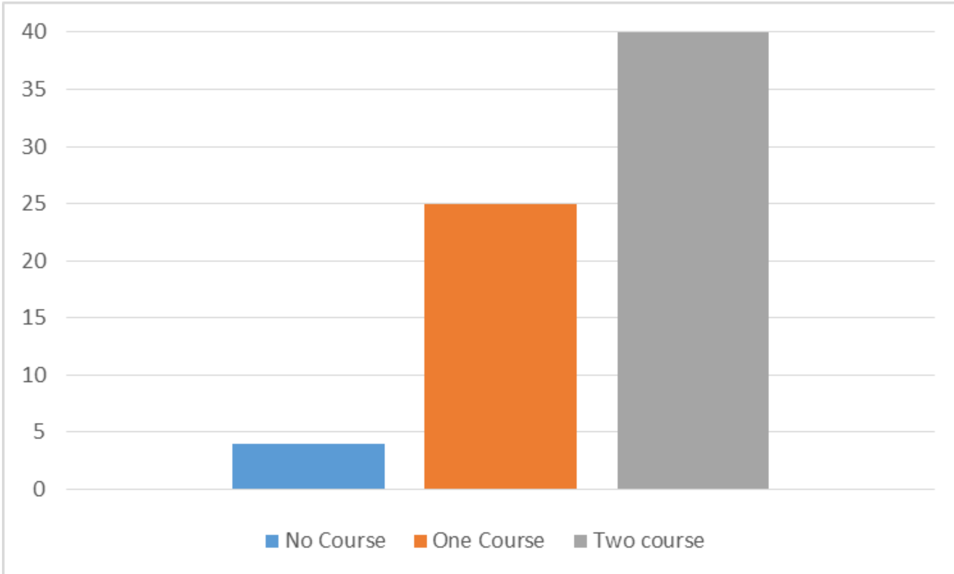


Fig. 1 Diversity student background in thermodynamics, 2012-14 and 2016

Table 1 shows the questions asked in the survey about the level of understanding and the knowledge of most topics covered in a two-semester course sequence in undergraduate thermodynamics and the results of responses given by students. The table also includes few topics that are not typically covered in undergraduate courses.

Students' perception of their level of knowledge in each topic area is presented in the last column in Table 1. The data indicate that the majority of students believed that they had adequate knowledge and understanding of: defining thermodynamic systems, distinguishing between various types of properties, applying the general equations for conservation of mass, conservation of energy, and entropy balance equation correctly to specific thermodynamic systems. Also the majority indicated that they knew how to use thermodynamic tables to evaluate properties of real fluids and ideal gases. However, a larger fraction of students had either a very limited knowledge or no knowledge about what is exergy, how to evaluate properties of mixtures, balancing chemical reaction equations, solving combustion problems, or conducting Psychrometric analysis. Very few students, or in some cases, none had any background knowledge about phase equilibrium, stability and metastable thermodynamics, or using thermodynamic thermodynamics relations to evaluate properties from p-v-T data.

Since the survey results represent only students' perception of their background knowledge in thermodynamics, it was decided to give a quiz at the start of semester to assess students' actual background knowledge in thermodynamics. After completing the student survey on the first day of class in spring 2017, students were asked to take a quiz on basic math and some of the topics covered in the undergraduate courses in thermodynamics. The quiz consisted of 28 questions that included 10 questions in basic math necessary for advanced thermodynamics and 18 questions related to the topics covered, in most part, in the first course in an undergraduate thermodynamics. The math section of the quiz included simple problems in differentiation, integration, and multi-variable calculus. The thermodynamics questions included problems in property evaluation, and application of general rate equations for mass balance, energy balance, and entropy balance to specific thermodynamics systems and processes, (e.g., closed system, open system, steady state process, adiabatic process, etc.). A copy of the quiz questions is included in Appendix A which contains the number of correct answers by students to each question. Partial correct answers to questions are counted as wrong answers. It should be noted the quiz was closed book and closed note, but necessary equations were provided in the quiz.

Table 1. Students' perception of their understanding and knowledge of topics typically covered in a two-semester undergraduate course in thermodynamics (student surveys spring semesters 2012-14 and 2016).

Rank your understanding, knowledge, or ability in the following areas as: 5 = excellent, 4 = very good, 3= good, 2= adequate, 1 = very limited to none.

	Knowledge of topic or ability	Points					NA	N	Ave. score
		5	4	3	2	1			
		Number of responses to level of							
1	Thermodynamic systems	11	17	19	15	7	0	69	3.14
2	Extensive and intensive properties.	7	11	19	22	10	0	69	2.76
3	Evaluation of properties using tables	11	15	21	14	8	0	69	3.10
4	Evaluation ideal gas properties from tables and equations	10	17	23	12	7	0	69	3.14
5	Evaluation real gas properties using generalized charts	8	12	17	11	21	0	69	2.66
6	Evaluation of properties, using the following software :								
	a. Interactive Thermodynamics	8	14	15	7	25	11	69	2.62
	b. EES	4	6	3	1	35	21	48	1.83
	c. Excel	6	11	7	3	25	18	51	2.41
	c. Other software	0	3	0	0	39	28	41	1.20
7	Conservation of mass	14	21	23	4	7	0	69	3.44
8	Conservation of energy	14	21	23	4	7	0	69	3.44
9	Second law of thermodynamics	10	17	26	10	7	0	69	3.18
10	Thermodynamic cycles	8	14	21	14	12	0	69	2.88
11	Exergy or availability	4	7	14	11	30	3	66	2.15
12	Evaluation of properties of mixture of ideal gasses	6	7	15	10	28	4	65	2.28
13	Evaluation of properties of mixture of real fluids	0	0	0	0	52	17	52	1.00
14	Chemical Reaction and Combustion	8	10	10	17	23	1	68	2.45
15	Psychrometric	6	8	11	14	26	4	65	2.28
16	Phase Equilibrium	0	0	7	4	54	4	65	1.28
17	Stability and metastable thermodynamics	0	0	0	0	58	11	58	1.00
18	Thermodynamic Relations	4	6	11	12	30	6	63	2.07

At the start of spring semester, 2017, thirteen (13) students participated in the survey. The participants included nine (9) MS students and four (4) PhD student. Eleven (11) had received their undergraduate degrees in ME and the other two had undergraduate degrees in engineering science and environmental sciences. Eight (8) students had received their undergraduate degrees from the author's institution, and five (5) had received their degrees from other institutions, including three from other countries. Figure 2 shows the diversity of student background in thermodynamics. Ten (10) students had completed a two-semester course sequence in undergraduate thermodynamics, two completed only one undergraduate course, and one had not taken a formal undergraduate course in thermodynamics. The prerequisites for undergraduate courses are strictly enforced by the automated registration system, but not for the graduate courses. The enforcement of the prerequisite for graduate courses are left to the faculty advisor of the graduate student and the instructor of the course. In this case the student without the official prerequisite had audited the undergraduate course in thermodynamics. Two of the students are returning to school to complete a graduate degree after more than 20 years of working in industry as engineers or holding positions as engineering managers.

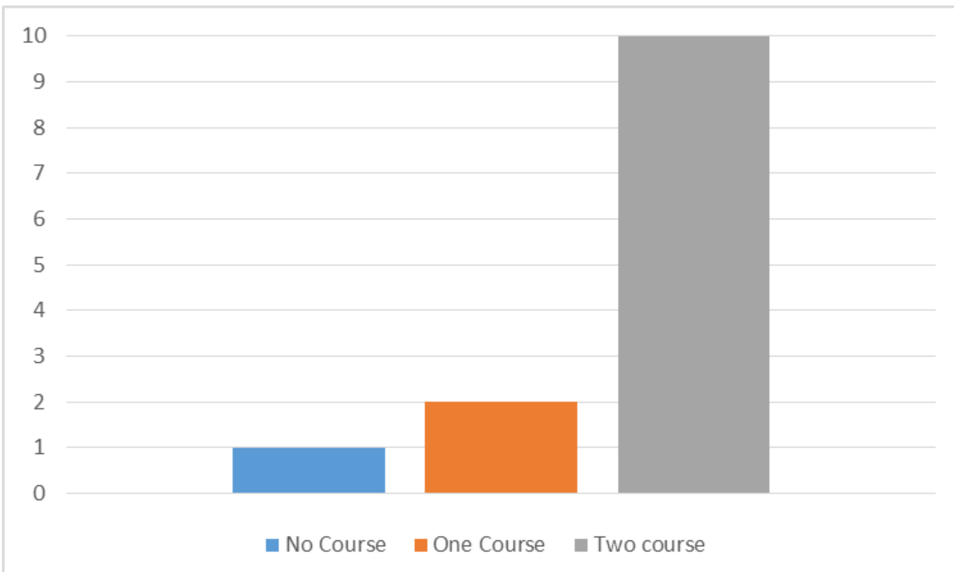


Fig. 2 Diversity student background in thermodynamics, spring semester 2017

Table 2 shows the questions included in the 2017 spring semester survey and the results of responses by students. Again the purpose of survey was to seek students' perception of their knowledge in some of the topics covered in a two-semester course sequence in undergraduate thermodynamics. Few questions were related to topics generally not covered in the undergraduate courses. Similar to Table 1 the last column in Table 2 gives the weighted average of students' perception of their level knowledge in each topic areas. The data shown in the Table 2 is similar to those in Table 1 for topics typically covered in the first course in thermodynamics. On the average, students enrolled in 2017 were more confident about their knowledge of the topics that are typically covered in the second undergraduate course in thermodynamics than those in the previous semesters. One reason might be that the majority of students in the 2017 class had completed a two-semester undergraduate course sequence in thermodynamics.

Table 2. Students' perception of their understanding and knowledge of topics typically covered in a two-semester undergraduate course sequence in thermodynamics (spring semester 2017).

Rank your understanding, knowledge, or ability in the following areas as: 5 = excellent, 4 = very good, 3= good, 2= adequate, 1 = very limited to none.									
	Knowledge of topic or ability	Points					NA	N	Ave. score
		5	4	3	2	1			
		Number of responses to level of							
1	Thermodynamic systems	1	5	3	3	1		13	3.15
2	Extensive and intensive properties.	5	2	6	2	3		18	3.22
3	Evaluation of properties using tables	3	4	2	2	2		13	3.31
4	Evaluation ideal gas properties from tables and equations	2	4	2	2	2		12	3.17
5	Evaluation real gas properties using generalized charts	1	4	3	4	1		13	3.00
6	Evaluation of properties, using the following software :								
	a. Interactive Thermodynamics	0	1	2	2	4	4	9	2.00
	b. EES	0	0	0	1	6	6	7	1.14
	c. Excel	1	2	1	0	4	5	8	2.50
	c. Other software	0	2	0	0	3	8	5	2.20
7	Conservation of mass	0	7	2	1	1	2	13	2.85
8	Conservation of energy	3	7	1	1	1		13	3.77
9	Second law of thermodynamics	0	7	3	2	1		13	3.23
10	Thermodynamic cycles	1	5	4	2	1		13	3.23
11	Exergy or availability	0	4	2	3	4	1	13	2.46
12	Evaluation of properties of mixture of ideal gasses	0	4	2	3	4	1	13	2.46
13	Evaluation of properties of mixture of real fluids	1	2	3	5	1	1	12	2.75
14	Chemical Reaction and Combustion	1	4		3	4	1	12	2.58
15	Psychrometric	0	4	1	2	5	1	12	2.33
16	Chemical Equilibrium	0	3	3	3	3	1	12	2.50
17	Phase Equilibrium	0	2	5	1	4	1	12	2.42
18	Stability and metastable thermodynamics	0	2	1	2	7	1	12	1.83
19	Thermodynamic Relations	2	3	3	1	3	1	12	3.00

Fifteen students took the background quiz at the start of the 2017spring semester. The results of the background quiz was surprisingly much worse than expected. Most students solved the differentiation and integration problems correctly, but few had difficulty differentiating integrating exponential functions such as e^{2x} correctly. Most students or in some cases the entire class did not completely answer the thermodynamics questions correctly. For example none of students completely answered the following question correctly. *For a single component fluid (e.g., water) in the two-phase saturation region, which of the following properties defines the state (are independent pair of properties)? Circle all correct pair of properties: a) P and v, b) P and s, c) P and T, d) v and x, e) T and x, f) u and v.*
Most students could not correctly simplify the following general rate equations as applied to a control volumes with single inlet and outlet under specified conditions.

$$\frac{dm_{cv}}{dt} = \sum_i \dot{m}_i - \sum_e \dot{m}_e \qquad (1)$$

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

$$\frac{dS_{cv}}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \dot{\sigma}_{cv} \qquad (3)$$

For example, one question on the quiz asked students under what conditions the process for a control volume with a single inlet and a single outlet will be isentropic. The question also stated that $s_1 = s_2$ is not an acceptable answer. The problem asked students to state specific conditions for simplifying equations (1) through (3) in order to show that $\Delta s = 0$. Only one out of the 15 students answered the question correctly.

One might question why this group of students performed poorly in the thermodynamics background knowledge quiz. There are several possible factors that have contributed to students' poor performance on the quiz. The quiz was not announced in advance allowing students to review some of the materials in advance. Only 50 minutes was provided for students to complete the quiz, hence the time might have been short for answering all questions correctly. Some students had completed their undergraduate thermodynamics courses a while back and had forgotten some of the materials. A quick refresher can remedy the problem for these students. A feasible reason is that some students have had a shallow understanding of the thermodynamics concepts when they completed their undergraduate course or courses. In addition students' preparation in thermodynamics were evaluated with respect to undergraduate courses at UTSA, but not all students had completed their undergraduate degree at that institution. In the future, questions similar to those given in the Fundamental Exam (FE) will be included to evaluate student's background knowledge in thermodynamics. But others questions such as simplifying Eqs. (1) through (3) as applied to specific applications are still important to be included in the quiz. Our experience has shown that some students cannot correctly simplify Eq. (3) to show that a process is isentropic. They sometimes apply equations for closed systems to open systems and vice versa.

Since some of the undergraduate thermodynamics topics are covered in Advanced Thermodynamics in more detail, the results of the background quiz gives the instructor an opportunity to focus more on the areas that students displayed lack of understanding of the basic concepts in thermodynamics. The instructor can make sure that those concepts are well understood by students when the topics are covered again in the graduate course.

Teaching a graduate course in thermodynamics to a group of students who have a diverse range of background knowledge in thermodynamics has been and still is a continuing challenge. A few students who had were taking the Advanced Thermodynamics course in previous years had almost no background in thermodynamics. For example, they did not know how to find properties from thermodynamic tables. Since many engineering programs in the United States and abroad require only a single course in thermodynamics for the undergraduate degree, only the first course in thermodynamics is required as a prerequisite for the graduate level Advanced Thermodynamics. Therefore, many students enrolled in Advanced Thermodynamics have completed only one course in thermodynamics while completing their undergraduate degree. But there are others in the course who have completed a two-semester course sequence in thermodynamics as an undergraduate and as a result they have the understanding and knowledge of more advanced topics in thermodynamics. To address this situation, the lecture and homework assignments have been designed such that the students with the weaker background in thermodynamics can learn the basic materials as quickly as possible. The course coverage is adjusted such that students with stronger background will not board, while other students are trying to catch up learning the basic concepts. Methods described in prior studies are used to force students to apply the most general thermodynamics equations, such as Eqs. (1) through (3), correctly when applied to thermodynamics systems.[4,5] For example in some homework and exams problems students are asked to start with the most general equations and simplify them as they apply them to specific thermodynamic systems (e.g., a gas in a piston and cylinder; fluid flow through turbines, compressors and heat exchangers; filling up a tank with a fluid from a supply line, etc.).

Selection of a textbook for the course is also a challenge. Many publishing companies have stopped publishing graduate level textbooks in mechanical engineering due to small demand. Some of the textbooks have been published many years ago with no new revisions. Only a few textbooks have been published since 2005. The Advanced thermodynamics textbooks by Annamalai, Puri, and Jog; Bejan; and Winterbone and Turan are few examples of more recent publications.[6-8]. The older textbooks include those by Wark; Callen; and Hatsopoulos, and Keenan.[9-11] Some of the older books such as the one by Wark are out of print, but they can be reproduced as special order. Unlike the undergraduate textbooks, the topic coverages are not very similar in Advanced Thermodynamics textbooks. For example, the textbooks by Bejan and Wark cover power cycles, but the textbook by Annamalai *et.al* does not. The author has used both textbooks by Bejan and Wark in his course in the past. The textbook by Annamalai *et.al* was adopted in spring 2014 and is currently being used again in spring 2017. It seems students had easier time following the material in the text book by Wark as compared to other text books. There are too much materials in each textbook to be covered in a single semester. Therefore, the instructor has a choice of selection of more advanced materials to be covered in the course.

The main topics covered in the Advanced Thermodynamics course are:

1. First Law of Thermodynamics
2. Second Law of Thermodynamics

3. Entropy Generation, Availability (Exergy) Exergy Analysis, and Exergy Destruction
4. Power Generation and Refrigeration
5. Thermodynamics Postulates
6. State Relationship of Real Gases and Liquids
7. Thermodynamic Properties of Pure Fluids
8. Thermodynamics Properties of mixtures and Psychometrics
9. Phase Equilibrium
10. Stability, stable and meta-stable systems
11. Chemically Reacting Systems.

The coverage of topics are more advanced than those covered in undergraduate courses. Many application of first and second laws to transient problems lead to first order differential equations. In most cases the differential equations can be solved by integration. The Advanced Thermodynamics course includes the review of the first law and second laws of thermodynamics. The topic on Thermodynamic Properties of Pure Fluids, includes the coverage Maxwell relations, evaluation of changes in enthalpy, internal energy, and entropy from P-v-T data as well as development of departure function from equation of state.

A textbook in Advanced Thermodynamics is adopted and is required for the course every semester. But some of the introductory lectures are from one of the popular undergraduate textbooks.[12] Some of the homework assignments are selected from the required textbook. Others are selected from other sources, including those developed by the instructor. To assist students with limited background in thermodynamics to catch up, the fundamentals concepts are quickly reviewed during the first two weeks of semester. Examples are used to show students how to use thermodynamic tables for evaluation properties. Simple problems are assigned early in the semester to help all students to learn the basic concepts and skills required in property evaluations. In some homework and exam problems, students are asked to simplify general thermodynamics equations for specific applications. Gradually more advanced materials are introduced and related problems are assigned. The midterm exams usually consists of two parts: in-class exams and take home exams. The in-class exam consists of shorter problems focusing on fundamental concepts. The take home exams are more complex and require more time for solution. In additions to the homework assignments, midterm exams, and a final exam, students are required to complete a project in the course. The final grade in the course was based on the following areas and weights

Homework and projects………………………	30%*
Two mid-term examinations ....…..	40%
Final Examination................................	30 %
Total ....…	**100 %**

Starting spring semester 2017, I>Clickers are being used in the class room as an active learning tool. Multiple choice or true/false questions are employed during the class period to evaluate students' understanding of fundamental concepts, and provide immediate feedback to students. For example the following true/false question was asked during one of the lectures.

Consider a tank containing saturated liquid water at 100 ^{o}C. The tank, through a valve, is connected to a supply line carrying steam at 200 ^{o}C and100 bar. The valve is opened allowing steam to flow into the tank until the pressure in the tank reaches 50 bar. For the entropy balance analysis, is $S_2 – S_1 = Q/T + S_{gen}$ a correct equation? (A) Yes, (B) No.

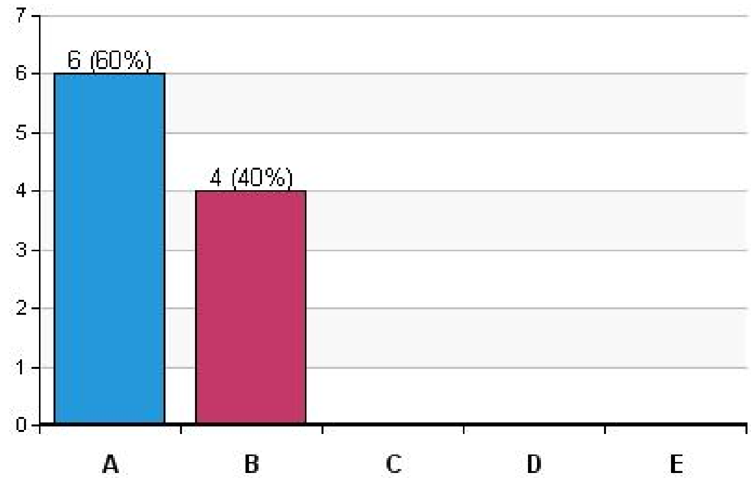


Fig 3. Students' responses to a true/false question

Figure 3 shows that 60% of students answered the question incorrectly. Students could see the results of their responses on the classroom screen. Instead of providing the correct answer, other questions were asked about the problem. Students we asked if the fluid in the tank can be modeled as an open system or closed system? All students answered the question by identifying the system as open. Then another question was asked which term in the given equation represents the entropy entering the system. By this point students who responded to the original question incorrectly, realized their mistake.

Student Feedback

At the end of spring semester 2016 a survey was conducted to seek students' opinion about the improvement of their knowledge of thermodynamics topics as the results of taking the Advanced Thermodynamics course. The questions and the results are presented in Table 3. The last column in the table presents the weighted averages of students' responses to each question. Table 3 shows that on the average the majority of students believed their knowledge of thermodynamics was improved as the result of taking the course. The survey also asked students if the homework assignment, exams, and the semester project were challenging. The result for this part of survey is presents in Table 4. The result indicates that students considered the homework assignments, the semester project, and take home midterm exam to be more challenging than the in-class exams. External problems were created by the instructor. The mid-term exams were consisted of an in-class part and a take-home portion.

Table 3. End of semester student survey (spring semester 2016).

Rank the improvement in your understanding and knowledge of thermodynamics in the following areas resulting from taking this course as:(5) vast improvement (4) adequate improvement (3) moderate improvement (2) slight improvement (1) very limited improvement									
	Improvement in knowledge of topic or ability	Points					NA	N	Ave. score
		5	4	3	2	1			
		Number of responses to level of							
1	Thermodynamic systems	6	6	7	0	0	0	19	3.95
2	Evaluation of properties using tables	8	3	6	1	0	0	18	4.00
3	Evaluation ideal gas properties from tables and equations	8	5	5	0	1	0	19	4.00
4	Evaluation real gas properties using generalized charts	8	5	4	2	0	0	19	4.00
5	Conservation of mass	4	7	4	3	0	1	18	3.67
6	Conservation of energy	5	7	4	2	0	1	18	3.83
7	Second law of thermodynamics	3	10	4	1	0	1	18	3.83
8	Thermodynamic cycles	2	5	8	2	1	1	18	3.28
9	Stability and metastable thermodynamics	2	8	5	3	0	1	18	3.50
10	Thermodynamic Relations (developing equations to evaluate properties from P-v-T data)	8	4	4	2	0	1	18	4.00
11	Exergy or availability	10	6	2			1	18	4.44
13	Evaluation of properties of mixture of ideal gasses	6	7	3	1	1	1	18	3.89
14	Chemical Reaction and Combustion	7	6	3	2		1	18	4.00
15	Psychrometric	8	4	3	2	1	1	18	3.89

Table 4. End of semester student survey (spring semester 2016)

Rank the following assignments or exams with numbers ranging from 1 (not challenging at all) to 5 (very challenging)									
	Knowledge of topic or ability	Points					NA	N	Ave. score
		5	4	3	2	1			
		Number of responses to level of							
1	Textbook homework assignments	11	7	0	0	0	1	18	4.61
2	External homework assignments	4	10	4	0	0	1	18	4.00
3	End of semester project	7	8	3	0	0	1	18	4.22
4	In class midterm exams	2	7	8	1	0	1	18	3.56
5	Take-home midterm exam	5	11	1	0	1	1	18	4.06
6	In class final exam	4	6	6	1	1	1	18	3.61

In the end of semester survey students were asked to make suggestions for improving the course in the future. Below is a list of suggestions:

- Perhaps recording lectures would allow students to refer to your lectures on line if they have a question about the concept. Many times the lecture explanation clarifies questions a student may have if they have forgotten what was said in the lecture.
- Please change the textbook. Your external problems are wonderful. Please give more external.
- Change the textbook
- Textbook should be changed. Rest of problems in the external sections were very good. Textbook problems sometimes were confusing.
- The textbook used was very hard to read. The homework problems often did not make sense. I would suggest using a different textbook.
- Use a different textbook.
- I didn't like the textbook we used. The problems in the book were often difficult to make sense of. I learned the most when we worked out examples in class.

Summary

Students with no thermodynamics background had a difficult time in the Advanced Thermodynamic course. Students with undergraduate degrees from other disciplines also had difficulties in the course. To address the problem of students taking the course with no background in thermodynamics, starting the 2016 catalog, the first course in the undergraduate mechanical engineering course is now required as a prerequisite for the course. The first two weeks of semester are used to review basic fundamental concepts in thermodynamics to allow students with weaker background in thermodynamics to catch up. A graduate level textbook has been adopted and required for the course. But students in general have difficulty with the materials as presented in some of the currently available textbooks. Other sources including materials from undergraduate textbooks were used in the lecture to help students understand more advanced materials in the graduate level textbook. In general those students who had taken a two-semester undergraduate courses sequence in thermodynamics performed better in the graduate course.

References

1. Karimi, A. and Manteufel, R., "Correlation of Prerequisite Course Grades with Student Performance," *ASEE-2013-7906, Proceedings of the 2013 ASEE Annual Conference*, June 23-26, Atlanta, Georgia.
2. Karimi, A. and Manteufel, R., "Assessment of Student Learning Outcome in an Introductory Thermodynamics course." ASEE-2012-5503, Proceedings of the 2012 ASEE Annual Conference, June 10-13, San Antonio, Texas.
3. Anderson, E., & Taraban, R., & Hudson, D., "A Study Of The Impact Of Visuospatial Ability, Conceptual Understanding, And Prior Knowledge Upon Student Performance In Engineering Statics Courses,", *Proceedings of the 2009 ASEE Annual Conference*, , , June 14-17, 2009, Austin, Texas.
4. Karimi, A., "An Approach in Teaching Applied Thermodynamics," *IMECE2008-6812, Proceedings of ASME International Mechanical Engineering Congress and Exposition*, November 2-6, Boston, MA
5. Karimi, A. and Manteufel, R., "Reinforcement of the Understanding of Fundamental Concepts in a Thermodynamics Course," *ASEE-2014-10626, Proceedings of the 2014 ASEE Annual Conference*, June 15-18, Indianapolis, IN.
6. Annamalai, Kalyan, Puri, Ishwar K. and Jog A, Milind, Advanced *Thermodynamics for Engineers, Second Edition*, CRC Press, New York, 2011

7. Bejan, Adrian, *Advanced Engineering Thermodynamics, Third Edition*, John Wiley & Sons, Inc., New York, 2006**.**
8. Wark, Kenneth, Advanced *Thermodynamics for Engineers*, *Second Edition*, McGraw Hill, Inc., New York, 1995
9. Callen, Herbert, *Thermodynamics and an Introduction to Thermostatistics*, John Wiley & Sons, Inc., New York, 1985
10. Hatsopoulos, G. and Keenan, J. H., *Principles of General Thermodynamics*, Krieger, 1965.
11. Winterbone, D.,Turan, A, Advanced Thermodynamics for Engineers, Elsevier Ltd. 2015
12. Moran M.J., Shapiro H.N, Boettner, D.D, and Bailey B.B, *Fundamentals of Engineering Thermodynamics, 7th Edition*, John Wiley and Sons, Inc., 2011.

Appendix A

Thermodynamics Background Quiz
Spring 2017

A. Solve the following math problems:

1. $y = 5 - 12x + 3x^{-2} + 6e^{2x}$ $\qquad \frac{dy}{dx} =$

11 correct answers *4 wrong or partially wrong answer*

2. $y = \frac{1}{x^3}$ $\qquad \frac{dy}{dx} =$

15 correct answers *No wrong*

3. $\int \left(4 + 2x - 3x^2\right) dx =$

11 correct answers *4 wrong or partially wrong answer (missing constant integration)*

4. $\int_{x_1}^{x_2} \left(4 + 2x - 3x^2\right) dx =$

12 correct answers *3 wrong or partially wrong answer*

5. $\int_0^1 \left(4 + 2x - 3x^2\right) dx =$

14 correct answers *1 wrong or partially wrong answer*

6. $\int_{x_1}^{x_2} 6e^{-2x} dx =$

8 correct answers *7 wrong or partially wrong answer*

7. $\int_{x_1}^{x_2} \frac{dx}{x} =$

14 correct answers *1 wrong or partially wrong answer*

8. What is the difference between an ordinary derivative and a partial derivative [e.g., $c_p = \frac{dh}{dT}$ and $c_p = \left.\frac{\partial h}{\partial T}\right)_p$]?

7 correct answers *8 wrong or partially wrong answer*

9. If $z = 4x^2 + xy - y^2$, evaluate $\left.\frac{\partial z}{\partial x}\right)_y =$

9 correct answers *6 wrong or partially wrong answer*

10. If $z = 4x^2 + xy - y^2$, express the total differential of z (dz in terms of dx and dy).
1 correct answers *14 wrong or partially wrong answer*

11. Under what conditions can you assume an ideal gas model (that is pv =RT or Z =1)? **Hint**: picture the generalized compressibility chart.

0 correct answers *15 wrong or partially wrong answer*

12. For most substances, the textbook does not provide tables of thermodynamic properties in the compressed liquid region. If the pressure and temperatures are given for substance in this region, how do you evaluate v(T, P), u(T, P), h(T, P), and s(T, P)? (6 points)

1 correct answers *14 wrong or partially wrong answer*

13. For a single component fluid (e.g., water) in the two-phase saturation region, which of the following properties defines the state (are independent pair of properties)? Circle all correct pair of properties:
P and v

P and s

P and T

v and x

T and x

u and v

0 correct answers *15 wrong or partially wrong answer*

14. For monatomic ideal gases c_p = 2.5 R. Evaluate the changes in specific enthalpy and specific internal energy for a system undergoing a process from T_1, p_1 to and T_2, p_2 (express the results in terms of R, T_1, and T_2). (6 points)

4 correct answers *11 wrong or partially wrong answer*

The following relations are equations for mass rate balance, energy balance (1st law of thermodynamics) and entropy balance (second law of thermodynamics) for control volumes. **Please use these equations to answer questions 15 through 18.**

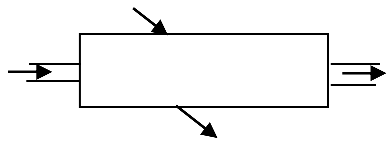
$$\frac{dm_{cv}}{dt} = \sum_i \dot{m}_i - \sum_e \dot{m}_e \qquad \text{(A)}$$

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

$$\frac{dS_{cv}}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \dot{\sigma}_{cv} \qquad \text{(C)}$$

14. Consider the schematic drawing of a general control volume shown below. Place m_{cv}, E_{cv}, S_{cv}, $\dot{m}_i, \dot{m}_e, \dot{Q}_{cv}, \dot{W}_{cv}, h_i, h_e$ in appropriate locations on the diagram

Fig A



6 correct answers *9 wrong or partially wrong answer*

15. Consider the control volume in Fig. A (question14) and equations A through C. Assuming a steady state and adiabatic process, simplify equations for mass rate balance, 1st law of thermodynamics, and second law of thermodynamics for the control volumes.

4 correct answers *11 wrong or partially wrong answer*

16. Consider the control volume in Fig. A (question 14) and equations A through C. Under what conditions the process will be isentropic (**Note:** $s_1 = s_2$ or similar statement are not the correct answer. You need to state specific conditions to simplify the appropriate equations to show that $\Delta s = 0$).

1 correct answers *14 wrong or partially wrong answer*

17. Consider the control volume in Fig. A (question14) and equations A through C. State the specific conditions that yield a constant enthalpy process (**Note:** throttling process, $h_1 = h_2$, or similar statements are not the correct answer, You need to state specific conditions to simplify the appropriate equations to show that $\Delta h = 0$).

3 correct answers *12 wrong or partially wrong answer*

18. Simplify equations A through C for a closed system.

1 correct answers *14 wrong or partially wrong answer*

19. (6 points)
    Define the followings in most general form
    a. Thermal efficiency for a power cycle
    b. Coefficient of performance for cooling
    c. Coefficient of performance for heating
    d. Turbine isentropic efficiency

e. Pump isentropic efficiency
f. Nozzle isentropic efficiency

0 correct answers *15 wrong or partially wrong answer*

20. Express the definition of thermal efficiency, η, for a power cycle operating between two thermal reservoirs: one reservoir at a high temperature of T_H and the other at a lower temperature of T_L.

0 correct answers *15 wrong or partially wrong answer*

21. In most general form, is the thermal efficiency, η, for the cycle described in question 20 =, >, ≥, <, or ≤ to $\left(1-\frac{T_L}{T_H}\right)$?

0 correct answers *15 wrong or partially wrong answer*

22. Under what conditions could you use the relationship $s_2 - s_1 = c_p \ln(T_2/T_1) - R\ln(p_2/p_1)$?

0 correct answers *15 wrong or partially wrong answer*

23. Under what conditions could you use the relationship $(T_2/T_1) = (p_2/p_1)^{\frac{k-1}{k}}$?

1 correct answers *14 wrong or partially wrong answer*

24. Under what conditions $(p_2/p_1) = (p_{r2}/p_{r1})$?

0 correct answers *15 wrong or partially wrong answer*

25. Define exergy or availability in words

0 correct answers *15 wrong or partially wrong answer*

26. For a single component fluid in the single phase region, $\left(\frac{\partial P}{\partial v}\right)_T$ $>\ ,=,\text{or} <0$?

1 correct answers *14wrong or partially wrong answer*

27 For a real fluid at the critical point $\left(\frac{\partial P}{\partial v}\right)_T$ and $\left(\frac{\partial^2 P}{\partial v^2}\right) >\ ,=,\text{or} <0$?

5 correct answers *10 wrong or partially wrong answer*

27 at the critical point

A $\left(\frac{\partial p}{\partial T}\right)_v = 0$

B $\left(\frac{\partial p}{\partial T}\right)_v > 0$

C $\left(\frac{\partial p}{\partial T}\right)_v < 0$

D $\left(\frac{\partial p}{\partial T}\right)_v = \left(\frac{\partial p}{\partial T}\right)_{sat}$

E none of the above

0 correct answers *15 wrong or partially wrong answer*