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# Why is thermodynamics so hard for students and what can an instructor do about it.

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# Why is Thermodynamics so Hard for Students and What Can an Instructor do about it

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## Abstract

The introductory engineering thermodynamics class often has a reputation for being difficult for students. The authors reflect on why it has such a reputation and how faculty can improve the course. This paper looks at three areas: student issues, instructor issues, and content issues. The challenges are broad and there is no simplistic summary of all of the challenges. It is easy to overlook fundamental issues, which will probably persist and be beyond the instructor's scope. One way to address all issues and change student perception is obvious: simplify the course. If one removes topics which students find difficult, the course will be become easier. Other than instructional restructuring and content reduction, the paper concludes wider systemic issues should be addressed to improve student satisfaction with the course.

## Introduction

Thermodynamics is a first semester junior-level course that has the widespread reputation for being difficult for students. The authors have taught thermodynamics courses and have documented approaches to improve student learning: spiral approach,[1] hands-on experiences,[2] focusing on fundamental concepts,[3] importance of prompt feedback,[4] active learning,[5] classroom engagement,[6-7] and practical challenges of assessment.[8] Thermodynamics is often taken promptly after prerequisite calculus and physics classes. Students often view the course as a filter and some call it a "gateway" course in mechanical engineering.[1] Faculty have sought to identify the challenges to student learning in thermodynamics and identify areas for improvement.[9,10] Students do not properly learn the concepts, including the most fundamental concepts like the First Law and the meaning of heat and work. Improved instructional strategies often promote active learning with repeated emphasis on common conceptual misunderstandings.[4,5,6,7,11,12] Recommendations to improve thermodynamics are often directed toward the conscientious instructor who is interested in improving student learning without compromising academic integrity. This paper discusses the issues in three categories: (1) student issues, (2) instructor issues and (3) content issues.

## Student Issues

Students can be their own worst enemy since they often are content to pass classes without learning and are prone to procrastinate. Yet, the students are a reflection of the educational system in which they are progressing. So is it less the students fault for being ill-prepared procrastinators and more the fault of the system that is allowing them to progress. They often are unprepared for a serious engineering course because they have earned credit for prerequisite courses without basic knowledge of prerequisite topics that are essential for a course like thermodynamics. This is obvious. If a student is well prepared for thermodynamics, they rarely struggle in the class. This is especially true in pre-requisite physics classes. Engineering physics classes are "calculus-based" yet many students earn credit in these classes without the most basic fundamental understanding of units, unit conversion, temperature, continuum assumption, mass, force, momentum, Newton's laws of motion, velocity, kinetic energy, gravitational energy, conservation of energy, pressure, hydrostatics, heat transfer, specific heat, work, differentiation and integration, etc. Thermodynamics is expected to build on the prerequisite knowledge gained in the calculus-based physic classes.

Similarly, students retain little from the pre-requisite mathematics classes. Many students do not know how to handle basic algebra, exponentiated terms, differentiation or integration. Yet within the first week of the thermodynamics class, homework problems require these math skills to handle a polytropic relationship like $P*V^n$ = constant. Similarly students can't handle exponents to transform algebraic equations like: $(a)^{(n-1)} = (b)^n$ to the equation $(a) = (b)^{(n/(n-1))}$. It is not always the higher-level math that stumps students. Often they do not understand the basic equation for a straight line with slope and intercept ($y = m*x+b$) and linear interpolation. It may come as a shock to faculty teaching at a flagship university that such deficiencies are possible, but they exist and are common in many community colleges and many non-flagship universities. This problem appears to be even more prevalent when there are high levels of transfer credits for prerequisite math/physics courses. Students are known to "shop" college courses. They don't shop for the highest level of learning but they shop for the easy "A" grade that requires the least amount of work and least amount of learning. In Texas, there is a widespread agreement that lower-level courses automatically transfer between institutions.[13] Flagship universities may have only a few students transferring courses or may accept only a few transfer students, thereby avoiding this problem. Yet for many state institutions, the quality of transfer classes is known to be widely variable. For many students, taking thermodynamics is like taking 3 (or more) classes all at the same time: physics, calculus and thermodynamics.

Students have stopped purchasing and stopped reading textbooks. It is increasingly common for a student to say they only study the power point slides for a foundational math or physics class. This becomes a challenge when they take a course like thermodynamics and believe they should be "taught" everything they were not taught in prerequisite courses. In the past, instructors helped students remediate deficiencies in pre-requisite material, often by referencing specific pages or sections in the physics or math textbooks used in prerequisite classes. However, this does not work if the student never used a book, does not own a book, and does not know how to learn from a book. Students have successfully passed courses without textbooks and they have no textbook to review when needed.

Scholastic dishonesty is a real issue. With the internet, it has become an overwhelming problem, especially when students take online courses. Students copy solutions from internet sites which have built a repository of solved problems for textbooks and for instructors. Often these sites are "for-profit" and charge a subscription fee. Because of the fee, it is difficult for an instructor to see what is on these sites without also paying a subscription fee. In the past, the students cheated primarily on homework, yet now it is very common to use these internet sites to cheat on exams. These for-profit companies provide online "tutoring" for all math/physics and many engineering classes.[14] Since this service is profitable, there is a growing number of new “online tutoring” services. On an exam, a student sneaks a phone into the room, takes pictures of the exam problems, submits the problems to online tutors, and often receives detailed worked-out-solutions so promptly that they are able to copy the solutions and submit the exam in the allotted 50- or 75-minutes for the face-to-face exam.[15] This is much more of a problem with online exams, especially if faculty follow the advice of the university, which is to allow extended time for students to take online exams. Some faculty claim that cheating has always existed in classes and use this claim as an excuse to do nothing. Many faculty are either ignorant of the reality of student cheating, or they have decided to turn a blind-eye to the problem. Many instructors have never prosecuted a case of scholastic dishonesty and based on discussion with many, they never will prosecute a case. Hence, it has become more widespread as more instructors do not care. This causes more problems for the vigilant instructor who tries to maintain academic integrity. When confronted with the charge of scholastic dishonesty, many students react in disbelief and shock since cheating is so widespread and they have cheated in many courses and it was apparent that the instructors knew they were cheating but didn’t care. Students are conditioned to think the educational system is a “game” where cheating is the norm, and they are dumbfounded when confronted with a charge of scholastic dishonesty. There have been numerous cases where students work in groups to cheat on exams, or have “ghost” accomplices during exams, and recently, one case involved a parent helping an engineering student cheat on a thermodynamics exam. Yes, a parent helped their adult child cheat on an online engineering exam. Numerous cases reveal a sad truth that the educational system, as well as the trends in society, view cheating as an accepted practice, especially if the authority figures do nothing to prevent it. In order to enroll in thermodynamics, the student will have passed 60+ semester-credit-hours of university courses. In the past, having passed so many courses was an indication that the student had demonstrated sufficient knowledge and maturity to be prepared for a course like thermodynamics, yet that is no longer a valid premise. It appears some students have cheated on every important prerequisite course and expect to continue this way through the engineering program.

## Instructor Issues

There are many instructor issues that cause the thermodynamics class to have a reputation for being hard. It must be acknowledged that some instructors do not devote the effort needed to teach difficult pre-requisite courses and assess student learning. Giving a clear lecture is only part of teaching. Assessing student learning is the harder and more important part of teaching a class, so some instructors cut-corners on assessment. This appears to be more true for newly hired tenure-track faculty and part-time faculty. Teaching a challenging lower-level course will have no meaningful impact on the metrics applied to evaluate the tenure-track faculty’s long-term employment at the university. So many tenure-track faculty devote minimal effort to lower-level undergraduate courses and strive to sufficiently please the students to earn acceptable evaluations of their teaching.

Part-time instructors teach many important math and physics classes. They often receive minimal compensation and often work full-time outside the college/university. They may teach because they enjoy being respected by the students. Assigning non-passing grades is very hard for some part-time instructors.  Part-time faculty who have high fail rates and low student evaluations of teaching often are not rehired.  This is a bigger issue in foundational prerequisite courses.

Full-time faculty can make thermodynamics hard by allowing “course-creep”.  This is often done unknowingly when the instructor devotes more time to subtle and esoteric topics that are abundant in thermodynamics.  Less time is devoted to the more mundane but foundational topics where the students struggle.  Instructors need to continually guard against “course-creep,” and this is discussed further in “course issues”.

The instructor is strongly impacted by the department chair, college dean, university provost and the overall academic system.  It is common for the “system” to be driven by a “more-for-less” approach to undergraduate courses.  This is probably the strongest driver influencing what the instructor does in the class and what students gain from a class.  Often, class sizes are increased because it is profitable for the system.  It should not need to be stated, but many disregard the obvious fact that it is not reasonable to expect the average instructor to provide a personal learning experience in a large class.  Some universities address this issue by having a “cap” on class sizes.  The authors of this paper recommend a “cap” of about 25 students.  This is based on years of instruction, trying to increase student engagement in a class.  It is not practical to engage students, especially reluctant at-risk students, when the class size is over 25.  This is especially true when one recognizes that learning is something that the student must accomplish.  The instructor only facilitates learning.  In many cases, and especially for “at-risk” students, the best thing a teacher can do is stop talking and listen to the student.  Students do not need more eloquent lectures or more interactive computer-based tools.  They often need time to formulate their questions and be heard by someone who knows the subject and is there to help them learn.  Student questions promote deep student learning.  Listening promotes student engagement and student learning.  The instructor must have time to listen to each student as they struggle to express ideas and questions.  Large class sizes diminish questions and diminish student learning.

It should be acknowledged that sometimes faculty are assigned to teach a course they should not teach.  Either they lack the background or they lack the interest to teach the course.  They may go through the motions of teaching, yet are ineffective.  Sometimes they are ignorant of their own ineffectiveness.  Sometimes they are disengaged from the students.  This problem is more common than one likes to admit.  One important foundational class with an ineffective teacher can have a big impact on a student’s success in many subsequent classes.

## Course Issues

In all courses, the instructor should continually question what is being taught and to what level it is being taught.  Here we identify some course issues specific to thermodynamics.  We do not address pre-requisite course issues.

When there is more than one way to solve a problem, the instructor should look to emphasize one method.  Giving more choices to students often makes the course more difficult.  There are many examples in thermodynamics, such as the introduction of the property enthalpy for constant pressure heating.  Students can solve these problem without enthalpy, by explicitly calculating boundary work and changes in internal energy to calculate the required heat transfer. Yet one can also combine boundary work with internal energy change to show the heat transfer equals the change in a new property called enthalpy. It would be better to delay the introduction of enthalpy, the new property, until the study of open systems.

Another example is the choice to use either temperature-dependent or constant-value specific heats for ideal gases. For an introductory course in thermodynamics, many student do not grasp the significance of the difference in these methods and often switch back and forth between methods in the same problem. An instructor can spend more time explaining and re-explaining when to use tables for u's and h's versus constant specific heats, but this takes valuable class time and places additional learning load on the students. It is recommended to introduce both methods, yet primarily use the simplest method for the majority of problems. For thermodynamics, it is recommend to use constant specific heat for ideal gas energy and entropy calculations.

Thermodynamics has many terms and definitions that are often clear to the instructor yet are confusing to students. It is helpful to streamline terms. As an example, instead of using "adiabatic", it may be better to say "without heat transfer". The instructor should repeatedly define and use expanded descriptions of terms to help struggling students. The same may be used when describing a constant pressure process, which is often called "isobaric". In contrast, thermodynamics can also have the opposite problem of having no clear definition for a term like "energy." It is a shortcoming of some thermodynamics textbooks that the term "energy" is assumed to be understood by the student, hence it is not defined in thermodynamics. This leaves many students to define energy in their own mind, and this is often done incorrectly. Students often think of "energy" as the capacity to do work, which is a better definition of "exergy".

In some cases, thermodynamics is hard because the concepts are hard and students often have numerous misconceptions. Many students think an isothermal process is a process without heat transfer. Some concepts cannot be jettisoned from the class in order to make it easier. The instructor can only provide clear and concise explanations for the thermodynamic topics, and emphasize common conceptual misunderstandings.

When students don't understand basic pre-requisite topics in math and physics, it is a mistake to reteach these topics as if the student is not responsible for basic prerequisite material. Re-teaching such topics appears to be widespread and leads to a reduction in essential thermodynamic topics. Some instructors find it difficult to cover basic cycles: Rankine, Otto, Diesel, Brayton, and vapor-compression cycle. This is a mistake. Cycles must be covered. When cycles are not covered the class is "gutted" and leaves the students with a poor impression of thermodynamics. Engineering thermodynamics must have a significant coverage of fundamental cycles, and more time should be devoted to cycles, not less. If a student lacks prerequisite knowledge, then the thermodynamics class should provide remedial learning opportunities for the foundational physics and math concepts. Thermodynamics does require student to handle exponentiated terms (algebra), does require students to differentiate (ordinary and partial derivatives) and does require students to integrate (p*dV and T*ds). There is no realistic way to teach the course omitting these topics, so one must provide additional recitations or learning opportunities to remediate these topics, while not dropping fundamental thermodynamic content from the course.

## Summary and Conclusions

This paper address how the average instructor can improve a thermodynamics course, especially if it has the reputation for being "hard" for students. This is a complex problem, and this paper tries to address the main issues in three areas: student issues, instructor issues and course issues.

For the students, the class is hard because: (1) students are under-prepared coming from pre-requisite physics/algebra/calculus classes, (2) students increasingly do not purchase and do not read textbooks, (3) students increasingly copy homework and/or use online resources to cheat on homework, and (4) more students are cheating on exams as an acceptable practice, especially in online courses. Many students have successfully completed 60+ semester credit hours of university work before they take a thermodynamics class. Thermodynamics is not the first college/university class they take. The most logical approach a student takes for a new class will be to repeat the same approach the student successfully used to pass previous classes. If it was successful in passing other classes, it should work in thermodynamics. Therefore, the problems with the students is mostly a reflection of the problems in previous classes. They have gotten this far with minimal effort and minimal learning. If thermodynamics is adjusted to be in line with previous classes, then it will lose the reputation for being hard, but that would be "gutting" the class and that is not recommended here.

For instructor issues, the class is hard because: (1) tenure-track faculty would be foolish to devote much effort to teaching the class as long as their future employment at the university will be decided on other performance metrics, (2) part-time faculty teach to be liked and respected, and often have little motivation to assess student learning (where students might fail the class) or to be diligent in upholding the academic integrity of the program (prosecuting a student for cheating is a very distasteful part of being a teacher), (3) experienced faculty may unknowingly allow "course-creep" where more material is introduced and more time is devoted to subtle and esoteric topics, so less time is devoted to topics that student struggles with, (4) the department chair/dean/provost/president have allowed the class sizes to bloat while they wishfully expect faculty to provide personal learning experiences to the students, so even the most dedicated instructor is placed in impossible situations, (5) some faculty are assigned to teach the class when they don't know the topic and/or don't want to teach the course.

For course issues, the class is hard because (1) there can be more than one way to solve a problem and having multiple ways make the course more difficult for struggling students, (2) there are many new terms and definitions in thermodynamics that the average student has little prior experience with, (3) the course requires students to really know algebra, especially how to handle equations with exponentiation, (4) the course requires students to really know differentiation, such as the difference between an ordinary derivative and partial derivative, (5) the course really requires students to know integration, especially integration of exponentiated terms, (6) the course often concludes without meaningful introduction of cycles which are at the heart of engineering thermodynamic, so the course appears to be a meaningless exercise in equation manipulation with obscure terms for which students lack physical intuition.

To improve the course, this paper offers limited suggestions which primarily focus on what is within the control of the instructor. The instructor should focus on the central elements of the course, which are cycles. It appears some instructors "run out of time" and do not sufficiently cover cycles. The instructor should not allow the course to devolve to a re-teaching of prerequisite topics, but provide remediation opportunities for students who forgot these topics without slowing the class. The instructor should look for ways to reduce the number of ways to solve a problem and avoid giving too many options to students. Too many options confuse struggling students. For example, when covering ideal gas property evaluations it is recommended to introduce but not emphasis the use of ideal gas tables that essentially account for temperature-dependent specific heats. The use of constant specific heats is sufficient for an introductory engineering thermodynamics course. Lastly, many things are beyond the control of the instructor and it is the institutional factors that often make the course "hard" for students.

## References


1. Manteufel, R., 1999, "A Spiral Approach for Mechanical Engineering Thermodynamics," Proceedings of the ASME International Mechanical Engineering Conference, Nashville, TN, Nov 14-19.
2. Manteufel, R., 1999, "Student Learning and Retention Initiative at UTSA in Thermodynamics," Proceedings of the ASEE Gulf-Southwest Annual Conference, Le Tourneau University, March 7 -9
3. Manteufel, R.D., 2000. "Hands-On Laboratory Experience in Introductory Thermodynamics," 61C3, Proceedings of the ASEE Gulf-Southwest Annual Conference, Las Cruces, NM, April 5-8.
4. Karimi, A. and R.D. Manteufel, 2014, "Assessment of Fundamental Concepts in Thermodynamics", ASEE Annual Conference, ASEE-2014-10626, Indianapolis, IN, June 15-18.
5. Manteufel, R.D., 2015, "Use of Conceptual Questions with Prompt Feedback in Engineering Thermodynamics", Proceedings of ASME International Mechanical Engineering Congress and Exposition, IMECE2015-52276, Houston Texas, Nov 13-19.
6. Manteufel, R.D. 2016, "Active Learning using a Classroom Response System in Thermodynamics", Proceedings of the ASEE Gulf-Southwest Annual Conference, Fort Worth, TX, March 6-8.
7. Manteufel R.D. and A. Karimi, 2017, "Active Learning in Thermodynamics by Leaving the Front of the Classroom", Proceedings of the ASEE Gulf-Southwest Annual Conference, Dallas, TX, March 12-14.
8. Karimi, A, E. Finol and R.D. Manteufel, 2019, "Bringing Uniformity in Assessing Student Knowledge in Two Sections of an Undergraduate Course in Thermodynamics", Proceedings of the ASEE Gulf-Southwest Annual Conference, Tyler, TX, April 10-12
9. Meltzer, D., 2008, "Investigating and Addressing Learning Difficulties in Thermodynamics", ASEE Annual Conference, AC 2008-1505, Pittsburgh, PA, June 22-25.
10. Dukhan, N. and M. Schumack, 2013, "Understanding the Continued Poor Performance in Thermodynamics as a First Step toward an Instructioal Strategy", ASEE Annual Conference, ASEE-2013-8096, Atlanta, GA, June 23-26.
11. Partanen, L. 2016, "Student Oriented Approaches in the Teaching of Thermodynamics at Universities – Developing an Effective Course Structure", Chem. Educ. Res. Pract. 17, 766-787.
12. Dukhan, N. 2016, "Framing Students' Learning Problems of Thermodynamics", ASEE Annual Conference, ASEE-2016-14790, New Orleans, LA, June 26-29.
13. www.tccns.org, Texas Common Course Numbering (TCCN) system, accessed 2/12/2021.
14. www.chegg.com, Chegg , accessed 2/12/2021
15. Manteufel, R.D., A. Karimi, and P.A. Bhounsule, 2020. "Use of Phones and On-Line Tutors to Cheat on Engineering Exams", Proceedings of the ASEE Gulf-Southwest Annual Conference, Albuquerque, NM.

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