A SPIRAL APPROACH FOR MECHANICAL ENGINEERING THERMODYNAMICS

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Thermodynamics can be described as one of the "gateway" courses in Mechanical Engineering (ME). A gateway course is one where student success in the course is highly correlated with overall success in the degree program. Each semester about 40-50% of the students enrolled in thermodynamics at the University of Texas at San Antonio (UTSA) fail to earn a passing grade of "C" or better. Hence, many students reevaluate their career goals and decide to retake the course, change majors, transfer to another institution, or drop out. It is obvious that failing a course is an indication of inadequate learning, but it is less obvious how to adapt instructional methods to improve student learning. At UTSA a spiral approach that emphasizes early and repeated presentations of life-affecting applications, has been adopted. This approach is affordable and effective, and can be adopted to other courses in engineering. The technique is especially well suited for a public university with open admission policies, because it focuses on motivating the high-risk, non-traditional students to be committed learners.

Background

The University of Texas at San Antonio is a comprehensive public metropolitan university serving the south central region of Texas that includes a largely minority populace. The origin of the students enrolling in thermodynamics over eight semesters is summarized in Table 1. The student's origin is determined by where they graduated from high school. The majority of the students consider San Antonio and South Texas their home. For this work, South Texas extends from San Antonio to Del Rio, Brownsville, and Corpus Christi. Students come from other regions of Texas and other states, primarily by relocating to San Antonio as a result of job transfers. Only a few foreign students attend UTSA.

Table 1. Where Students Entering Thermodynamics Graduated from High School

Semester	San Antonio and South Texas	Texas and United States	Foreign
Fall 94	75%	22%	3%
Spring 95	86%	12%	2%
Fall 95	74%	22%	4%
Spring 96	75%	22%	3%
Fall 96	53%	47%	3%
Spring 97	77%	23%	0%
Fall 97	43%	42%	15%
Spring 98	65%	20%	15%

To quantify the problem in thermodynamics at UTSA, the failure rate of students is shown in Table 2. The percentage of students failing to earn a passing grade of C or better since the fall 1994 semester is shown. On average about 45 percent of the students fail thermodynamics. Students failing the class are those earning grades D or F and those withdrawing after the University census date. At UTSA, the census day is during the third week of class and the students can withdraw from a course as late as the last day of the ninth week. In many cases, a student drops a class during the first two weeks during add/drops, and those are not counted as having failed the course.

Table 2. Percentage of Students Failing Thermodynamics at UTSA

Spring 95	49% of 41
Fall 95	37% of 38
Spring 96	50% of 32
Fall 96	25% of 32
Spring 97	29% of 17
Fall 97	53% of 25
Spring 98	52% of 25
Fall 98	50% of 38
Spring 99	52% of 48

It is recognized that UTSA and other similar Universities suffer from poor student learning and subsequent student retention. Root causes for the lack of academic success are varied, but two key issues are preparation and commitment.

The academic background of many students can be described as weak, particularly in mathematics and sciences. In some part, the lack of strong academic skills can be attributed to factors that are beyond the control of the instructor teaching thermodynamics. One factor is UTSA's relatively open admission policy where average high school students are admitted. In addition, many of the students are older than normal and have attended different Universities and community colleges. Frequently, the students work at least part-time while attending UTSA, take a minimum of courses per semester, or take semester breaks. In many cases, important prerequisite courses have been passed over two years previously. Approximately thirty percent of the students enrolling in thermodynamics having passed at least one important math or physics prerequisite course at a different university or college. In summary, the academic preparation of the students is varied and is challenging for the faculty. In addition, the instructor has little or no short-term control on the make-up of students enrolling in the course.

Without argument, the academic preparation of students is important, and students with weak backgrounds and poor performance in prerequisite courses are likely to be unsuccessful in demanding engineering courses. However, the instructor has few options for dealing with the weak academic preparation of a few of the students in a class except performing a more extensive review of prerequisite topics. This would penalize the well-prepared students and would diminish course content. Both of these are unacceptable.

For practical reasons, the instructor can not affect the preparation of students entering their class in the immediate future. One must work with the diverse background and preparation of the current student population.

Motivation

The most effective strategy to improve student learning is by motivating students to be committed learners. Assuming the student possesses a basic intellectual capacity, a motivated student can overcome a poor or "spotty" academic background. Similarly, a motivated student will be more disciplined to complete assigned homework and not be prone to falling behind. Once a student falls behind in thermodynamics, it is very difficult to catch-up. But how can students be motivated? It is proposed that students can be motivated by introducing life-affecting applications early and repeatedly in the class.

Life-Affecting Applications

Life-affecting applications pique the interest of students. In thermodynamics, it is relatively easy to find these applications, but they are equally easy to de-emphasize or introduce late in the semester. To emphasize these applications, a "spiral" approach to thermodynamics has been developed as illustrated in Figure 1.

In the spiral approach, thermodynamics is divided into four main topic areas, largely following the topics in the textbook [1]. An arrow in the figure indicates each lecture. The distance from the center to each arrow indicates the level of detail for the topics covered in the lecture. Early in the semester, all of the important concepts are covered. As the semester progresses, topics are revisited with increasing emphasis on quantitative skills and application of the concepts.

All of the most important topics are covered in the first lecture. If it is important, it is covered in the first lecture. The first and second laws of thermodynamics are described as clearly and concisely as possible. The purpose of the first lecture is to present an overview of the course, and more importantly to introduce life-affecting applications. A typical electric generating plant, air conditioner, internal combustion engine, and aircraft jet engine are explained. All of these applications can be related to industries and jobs in San Antonio and south Texas. Whenever possible, the instructor will describe a student who recently graduated and now is working as an engineer in one of the fields. Here, an attempt is made to link the course material with the very basic desire of the student to earn a degree and land a good job with a good salary.

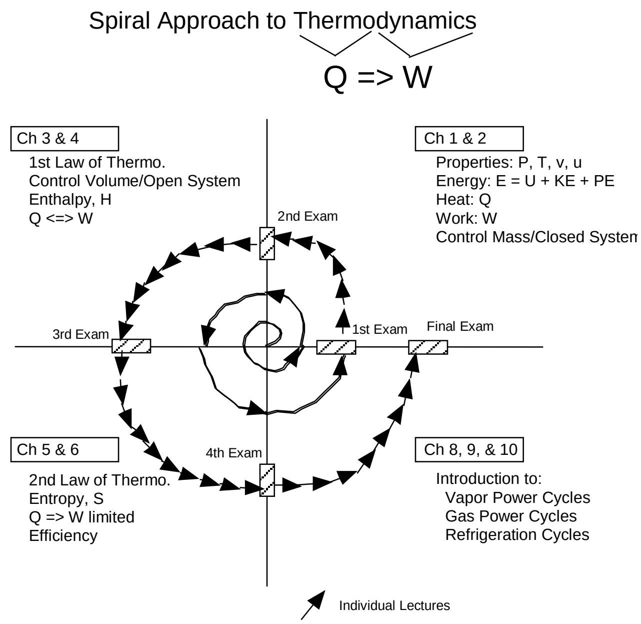


Figure 1: Spiral Approach to Thermodynamics with Early and Repeated Emphasis on Life-Affecting Applications

A copy of Figure 1 is given to each student along with the other handouts on the first day of class so that they can understand the approach being taken in the course. The students are told that important concepts, will be repeatedly emphasized throughout the semester.

One important aspect of the spiral is that important topics are repeated, without excessive reference to what has already been introduced. This is possible because the level of detail increases during the semester. Because of the overview, the students have a better appreciation for precise definitions and quantitative calculations.

The first exam is purposefully easy for the student who attends lectures and actively listens. However, a surprisingly large number of students fail this exam and this serves as a wake-up call that the material is important, the course will be rigorous, and the students must demonstrate mastery of the material in order to pass the class. The first exam on the 6^{th} day of the class normally accounts for 10% of the overall grade, so if a student fails, they can recover readily.

Emphasis on life-affecting applications is not a new concept in engineering education. Application problems are scattered throughout many excellent textbooks and are emphasized in courses. What is relatively new is that the method is adopted for the entire semester. The applications problems are introduced early and simple analyses performed early for these important applications.

This approach is largely derived from software development concepts. In the traditional waterfall model of software development, the process is described by a sequence of steps such as: requirement specifications, functional analysis, implementation, testing… The success of each step depends on results from earlier steps. Less than desirable results can often be traced to errors or oversights in earlier steps. The spiral method is an alternative approach for software development [2]. This approach is motivated by the fact that specifications are often inexact or incomplete. In response, the spiral approach strives to learn and improve the specifications, requirements and functionality through prototyping stages. One tries to obtain a handle on the overall problem as early as possible. One also repeatedly improves the final software product by revisiting stages of the typical waterfall model, until a final spiral can be completed with the best understanding of the problem possible.

From the student's perspective, they often do not understand or appreciate the detailed definition of terms or concepts that are rigorously covered in the first few chapters of a typical thermodynamics textbook. As such, they may fail to grasp these ideas and subsequently pay the price with less that satisfactory performance in subsequent topic areas. The remedy is to introduce the main concepts early and begin developing analysis skills. This means that one applies conservation of mass, first law, and second law principles as early as possible. The students use enthalpy and entropy, without a detailed presentation of the derivation of these concepts. Students begin to appreciate the utility of the material and the preciseness of more exact definitions and derivations.

Other traditional instructional methods are retained with the spiral approach. In particular, extensive use of lectures, homework, exams, and tutors are used. These are considered time-tested and effective methods. A few adaptations are discussed here to clarify the most effective use found by the instructor, and how they are used to help the students become more effective learners.

Lectures

Lectures are effective at communicating with a large number of students. Because the class size ranges from 30 to 50 students, the communication is essentially one-way. The primary drawback of a lecture is that students can become passive and their attention wanders. To counter this, the class is scheduled to have frequent meetings of short duration (MWF for 50 minutes instead of TTh for 1 hour and 15 minutes).

Lectures are peppered with questions that are mostly trivial and designed to keep the student's mind active. The questions early in the semester link thermodynamics and their current life-style. Lectures emphasize how things work, such as an automobile engine, jet engine, air-conditioner, and electrical power plant. This often sparks a sincere interest in a hand-full of students who participate in the class by answering questions. The quieter students sense the practical importance of the topics, the genuine interest of fellow students, and the instructor's sincere interest in having students learn. The mood of the class is often set in the first week of class and retained throughout the semester.

Exams

Using the spiral approach, four in-class exams are given during the semester as well as a comprehensive final. It is believed that frequent exams are effective at helping students stay on-track and helps many from falling behind. The topics in thermodynamics build on each other, so that a lack of learning early concepts continues to undermine the ability to master subsequent concepts.

Homework

In addition to numerous exams, homework is assigned, collected, graded, and promptly returned to the student in the traditional manner. A large number of homework problems are assigned to provide the student with frequent feedback on their performance. If the student works the homework, they should be prepared for the exams.

There is a strong correlation between homework scores and exam scores. When possible, the relationship between homework and exam performance is quantified and provided to the class during the semester. Figure 2 shows one such feedback. Prior to the first three exams, eight homework sets were collected and graded. Each exam was worth 100 points and homework was worth 10 points. The cumulative homework score is strongly correlated with cumulative exam score. Although faculty may not consider this surprising, the average student who neglects homework is given another wake-up call.

Figure 2 also highlights the impossibility of reaching every student. A few students do not do the homework and subsequently fail the exams. The worst performance was by a student who did no homework, worked each exam, and earned a score of zero on both homework and exams. As incredible as it may appear, the student filled each page of the exams with analyses so wrong that no partial credit was assigned for the effort. After reviewing the student's academic record, it was found that six attempts were needed to pass Statics, Dynamics was attempted eleven times, Solid Mechanics twelve times, and Thermodynamics seven times. In most universities, the student would be dismissed. Passing grades in non-engineering elective courses, and the University policy of counting only the highest grade in the computation of the overall GPA, allowed the student to continue. Regardless of this student's performance, it is clear that no teaching style or instructional method will reach all of the students. Students will learn the material only when they exert themselves.

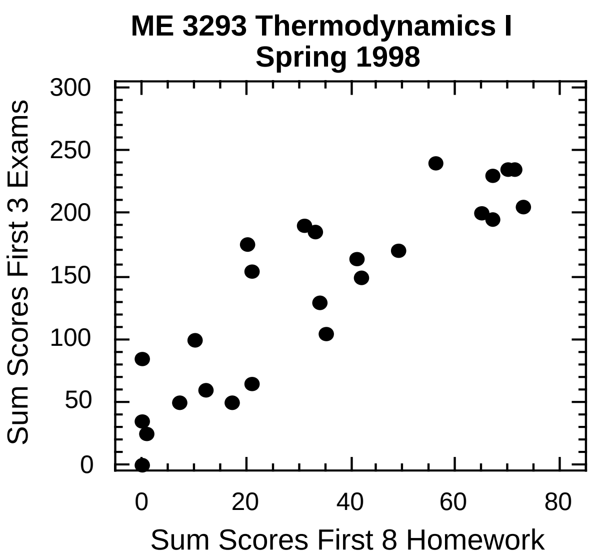
Figure 2. Correlation between homework and exam performance.

Tutors

Tutors for thermodynamics are used to help students who want to learn and master the material. Because of the lack of funds, it is difficult to pay students to act as tutors. However, tutors are considered important and funds are often scraped together each semester. Hopefully the University will appreciate the importance of tutors and support them in the future.

As implemented, tutors are available during extended hours in a small classroom (not an office). The room provides table space, chairs, and plenty of marker board. The tutor does not act as a teaching assistant and is instructed to avoid lecture-style demonstrations of problem-solving skills. In contrast, the tutor is to be question-driven. The questions can be trivial, such as "Can you explain how to solve this problem"? But the students are expected to initiate the discussion. Students are also encouraged to visit the tutor in small groups, and talk with each other as much as with the tutor.

The benefits of a tutor cannot be understated. The most important benefit is that tutor help students get "un-stuck" when solving complex problems. In many cases, students are uncertain about the approach needed or the first step to be taken. The tutor acts as a sounding board that keeps the student from being isolated, frustrated, and depressed. By avoiding these problems, the student is less likely to give-up and drop out of the course.



Another significant advantage is the camaraderie that develops among students. This may appear trivial to faculty from universities with full-time students living on or near campus, but for a commuter-dominated university this is significant. In many cases, the friendships make the college experience fun and rewarding. Problem solving in teams builds camaraderie. Many times the students feel comfortable in the room where the tutor meets, so they socialize between classes.

Summary

Student feedback has been overwhelmingly positive. On the instructor evaluations, students frequently write that the overview presented during the first two weeks of class initially appeared overwhelming, but the first test was straightforward and helpful. Only positive comments about the overview and the first exam have been received to date.

The overall effect on the "mood" of the class cannot be understated. In a typical class of 30-50 students, a handful of students have some experience and a sincere interest in power plants, engines, air conditioners, or jet engines. When just one or two students genuinely express interest in an application, the atmosphere changes. The change is hard to describe. Initially, the students are apprehensive about the course and instructor, and exhibit an indifferent attitude. But when the discussion reveals a genuine interest by at least one student, it is as if all of the students are awakened. In many cases, they become excited about the course material and are more committed to learning the material, passing the course, and continuing their education.

References

[1] M.J. Moran and H.N. Shapiro. Fundamentals of Engineering Thermodynamics, 4th Edition. Wiley. 1999.

[2] B.W. Boehm, Spiral model of software development and enhancement. IEEE Engineering Management Review 23(4):69-81, 1995.

Acknowledgments

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