2006-678: LESSONS LEARNED FROM DEVELOPING AND TEACHING AN INTEGRATED THERMAL-FLUIDS COURSE

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Lessons Learned from Developing and Teaching an Integrated Thermal-Fluids Course

Introduction

The Mechanical Engineering program at the United States Military Academy at West Point, New York, recently implemented a revised curriculum designed to reinforce engineering fundamentals and to offer students greater choice of sub-disciplines for in-depth study. One initiative associated with the revised curriculum was the integration of the courses, Thermodynamics and Fluid Mechanics, into a two-course thermal-fluid systems sequence. The first course in the sequence, ME311 (Thermal-Fluid Systems I) was taught for the first time during Fall 2005. This paper describes the course development process and the global learning structure on which the course is based to introduce and reinforce fundamental concepts. Additionally, this paper presents advantages and challenges associated with teaching a course that integrates Thermodynamics and Fluid Mechanics. Course feedback provides student perspective on the learning experience.

Background

Thermodynamics and Fluid Mechanics have been required courses in the USMA curriculum for well over a half century. Through the Class of 1979, all cadets were required to take both courses. Beginning with the Class of 1980 only those students interested in furthering their studies in engineering took both Thermodynamics and Fluid Mechanics. All other cadets took a new course, Thermofluid Dynamics (ME304), that covered selected topics in thermodynamics and fluid mechanics to provide "essential engineering knowledge necessary to understand the complex mechanical world of the U.S. Army".[1] Curriculum revision in the late 1980s required all non-engineering majors to take a five-course engineering sequence comprised of five courses from one of the ABET-accredited engineering majors. Since it was not an ABET-engineering course, ME304 was no longer needed and consequently was dropped from the curriculum. Beginning with the Class of 2005, the required engineering sequence for non-engineering majors was reduced from five courses to three courses. In most cases, all engineering sequence courses were decoupled from courses taken by engineering majors. For the three-course mechanical engineering sequence, the mechanical engineering faculty developed a new course, Introduction to Thermal Systems with Army Applications (ME350) that includes fundamental concepts of thermodynamics and fluid mechanics associated with Army equipment. The purpose of both ME304 and ME350 was to present topics from thermodynamics and fluid mechanics in a single course to acquaint non-engineering majors with technologies associated with Army equipment.

Cadets choosing an ABET-accredited curriculum take engineering courses associated with their major. As shown in Table 1, engineering disciplines requiring cadets to take a course in Thermodynamics and in Fluid Mechanics were Chemical Engineering, Civil Engineering, Engineering Management (Mechanical Engineering Track), Environmental Engineering, Mechanical Engineering, and Nuclear Engineering. Topics in Thermodynamics and Fluid Mechanics are fundamental for more advanced courses in these engineering disciplines. Systems Engineering majors only took Thermodynamics. USMA's course in Thermodynamics (ME301) introduced ideal gas/steam/refrigerant properties; mass and energy conservation principles and the second law for closed and open systems; cycles (Rankine, Brayton, Otto, Diesel, Vapor Compression Refrigeration); and psychrometrics.[2] The course in Fluid Mechanics (ME362) included fluid properties; hydrostatics; mass, energy, and linear momentum conservation principles; modeling and similitude; internal flow; external flow and drag; open channel flow; and compressible flow. The subject matter in each course was taught as distinct topics from either the thermodynamics or fluid mechanics perspective.

Based on course and curriculum assessments and the broadening of the mechanical engineering discipline, the mechanical engineering faculty at USMA proposed several changes to the mechanical engineering curriculum. One proposed change was to integrate ME301 and ME362 into a two-course sequence: Thermal-Fluid Systems I and II. Van Poppel et al. [3] discuss advantages to integrating courses. The primary goal of this integration was to improve student grasp of fundamental principles underlying both thermodynamics and fluid mechanics by applying these principles to integrated thermal-fluid systems rather than to distinct thermodynamic and fluid mechanic systems. Thermodynamics and fluid mechanics are based on the same fundamental conservation principles: conservation of mass, momentum, and energy. Students taking distinct courses in thermodynamics and fluid mechanics many times fail to recognize the common basis. By teaching the basic concepts and then applying the concepts to an integrated thermal-fluid system, students will better internalize these fundamental concepts. This sequence is different from ME350 in that the depth of study is much greater and topics are introduced from a systems approach.

As shown in Table 1, a consequence of integrating courses was some engineering majors opted to require their majors to take only the first course in the two-course sequence. Civil Engineering, Engineering Management, and Environmental Engineering added another discipline specific course to their curriculum in lieu of taking both courses in the sequence.

Table 1: Thermodynamics and Fluid Mechanics Requirements for Engineering Majors

Major	Thermodynamics	Fluid Mechanics		Thermal-Fluid Systems I	Thermal-Fluid Systems II
Chemical Engineering	Required	Required	→	Required	Required
Civil Engineering	Required	Required	→	Required	Not offered
Electrical Engineering	Elective	Elective	→	Required	Not offered
Engineering Management (Mechanical Engineering tract)	Required	Required	→	Required	Not offered
Environmental Engineering	Required	Required	→	Required	Not offered
Mechanical Engineering	Required	Required	→	Required	Required
Nuclear Engineering	Required	Required	→	Required	Required
Systems Engineering	Required	Not offered	→	Required	Not offered

As indicated in Table 2, integrating ME301 and ME362 into ME311 and ME312 resulted in a 23% drop in overall enrollment.

Table 2: Enrollment Changes

Old Course	2004-2005 Enrollment	New Course	2005-2006 Enrollment
Thermodynamics (ME301)	206	Thermal-Fluid Systems I (ME311)	208
Fluid Mechanics (ME362)	176	Thermal-Fluid Systems II (ME312)	88
Total	382	Total	296

Course Structure and Content

One of the most challenging aspects of integrating Thermodynamics and Fluid Mechanics in ME311 was structuring the content. The type and number of topics covered in the course were determined in advance by a committee that developed the structure for both courses, ME311 and ME312. Therefore, the next step was to sequence the major topics properly to achieve both an integrated curriculum and a curriculum that flowed logically from topic to topic.

In the ME311 development process, several approaches to the course sequence were discussed. The discussions started with a list of all the topics, without concern for structure, as depicted in Figure 1.

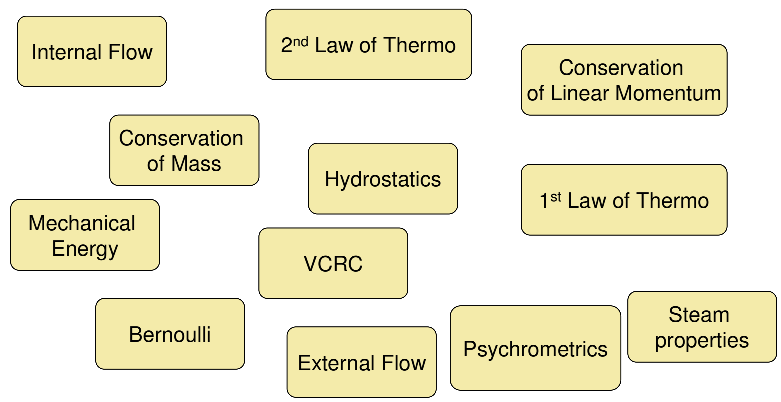

Figure 1: Course Topics without Structure

One obvious structure was to split the topics in a traditional way into a Thermodynamics block and a Fluid Mechanics block, as depicted in Figure 2. This approach offered two advantages. First, most of the Thermal-Fluids textbooks support this type of course structure. Second, with the two disciplines separated it is easier to structure the course in such a way to avoid any overlap of symbols, and there is a clear distinction between the subjects. However, this approach would negate any of the positive effects of integrating the material in the first place and would send the wrong message. The purpose of integrating the two disciplines was to gain efficiencies and to showcase the fact that Thermodynamics and Fluid Mechanics were simply different ways to look at the same two fundamental concepts: energy and losses.

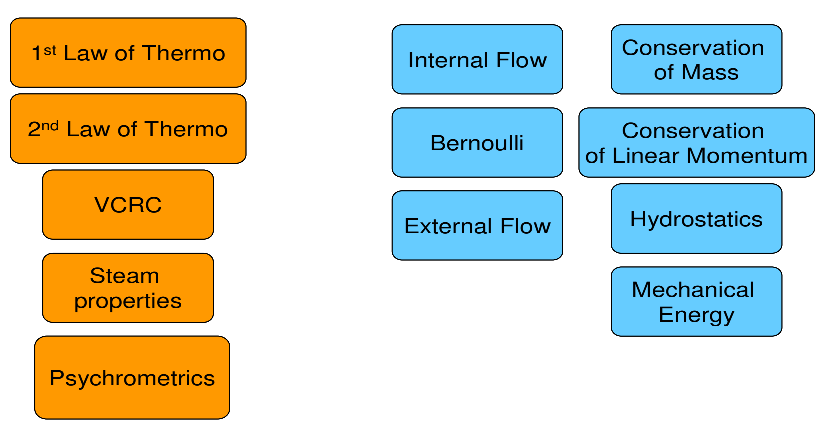

Figure 2: Topics Divided along Traditional Lines

Finally, an alternate approach was discussed and ultimately used to develop and structure ME311. The idea behind this approach was to find and develop real-world case studies as a focal point for the course curriculum. The case studies would be systems that incorporate Thermal-Fluid principles and applications and that are easy for students to understand and visualize. The three case studies chosen for ME311, which appear in Figure 3, are an AH-64 Apache Helicopter, the West Point steam power plant, and basic air-conditioning systems.

Figure 3: ME311 Case Studies

This approach provided a rationale for presenting and understanding the material beyond a purely academic endeavor. Students were actually interested in learning how systems that they may see and with which they may interact work. This also helps students who like to see things in a global sense. In a text on engineering education, Wankat and Oreovicz (1993) discuss different learning styles. One way to compare learners is whether they tend to learn topics sequentially and then see the big picture later, or if they tend to see things globally first and add in the details later.[4]

The case study approach to teaching appeals to global learners initially by offering them the big picture up front. For example, a class on the Bernoulli equation began with the question 'How does a pilot know how fast the aircraft is traveling?' A discussion initially ensued about how a speedometer on an automobile functions and why an aircraft cannot use the same method. Then the idea of the pitot-static system on the aircraft was introduced and pictures of the pitot tube from a helicopter were displayed. Finally, an airspeed indicator from an actual aircraft was shown in class with the two holes in the back of the instrument highlighted. Using the First Law of Thermodynamics, the class analyzed the pitot tube using a Control Volume approach to derive the Bernoulli equation and discuss the theory behind the pitot-static system on an aircraft. Thus the sequential learner also was satisfied by deriving the principle in class.

Second, the case study approach provides structure to the material in a way that avoided potential confusion caused by integrating the two disciplines. Instead of simply introducing material in a haphazard fashion, topics were presented in order to analyze a question posed by instructors about the case study. An example of the linkage between Thermal-Fluids topics and the helicopter case study appears in Figure 4.

This approach has several advantages. First, the course is able to leverage real-world systems to help explain topics that are often intangible and difficult to understand for undergraduate engineering students. For example, it was much easier to understand the concepts of thermal and mechanical losses in turbomachinery and pipe flow after walking through the steam power plant at West Point, feeling heat emanating from machinery, and viewing the complexity of the pipe networks in the plant.

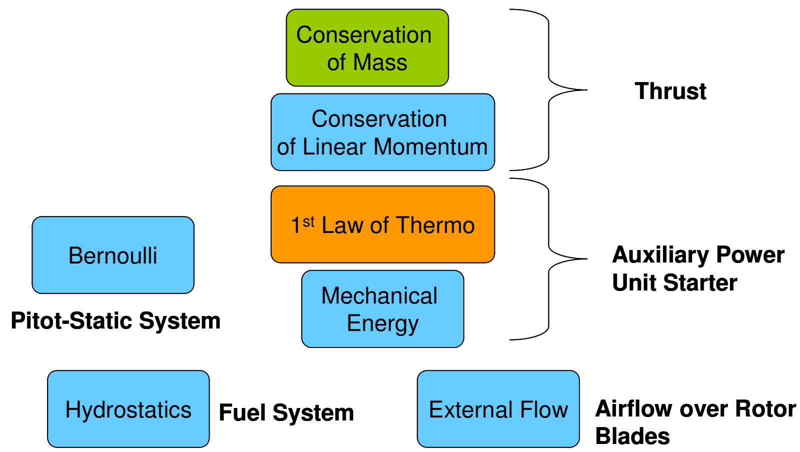

Figure 4: Helicopter Case Study Topics

The other advantage of this approach is that it incorporates problem-solving and a problem-solving methodology into almost every lesson. Each lesson or block of lessons began with a question posed to the students about an aspect of the current case study. The remainder of the lesson would be spent applying basic principles to answer the question at hand while teaching the pertinent Thermal-Fluids concepts. The students were exposed to a problem-solving methodology, and more importantly, a sense for how to analyze a real-world system. Often, engineers are taught about laws and theories and the underlying assumptions behind them without understanding why the assumptions and simplifications are important to the problem. The case study approach highlights the need to make rational, effective assumptions in the pursuit of a solution to a problem.

Another advantage of presenting the material as discussed is the ability to focus on the application of the lesson to actual engineering situations or case studies. This is separate from an integrated design that serves as the culmination for the course; the case study approach used in ME311 presented a framework from which to motivate each lesson.[5] The use of case studies was isolated to the classroom and the presentation of the material and hence was fundamentally different from the popular business-school approach of using case studies as a method for lesson preparation.[6] Jensen et. al. discussed extensively using a case-study approach for an advanced thermal-fluid sciences course, but chose not to extend that to their introductory course.[7] The analysis of commercial turbofan aircraft engines, refrigeration and HVAC systems and automotive engines both motivate students to gain physical intuition into the applied thermal-fluid sciences as well as to encourage in-depth questions.[8]

The case study approach lent itself to a Just-in-time method of instruction. In other words, material was presented only when it was needed to solve a problem or explain an aspect of the case study. As lessons were developed, material was incorporated into the case study blocks and individual lessons as necessary. However, there remained certain topics and objectives so fundamental that analyzing the case studies without the requisite background material became cumbersome. As a result, each major block of instruction started with introductory concepts to provide the students with a common engineering language and a set of tools to facilitate discussion of the case study topics.

Just-in-time teaching (JITT) presents material in such a format that the distractions to cognitive learning are minimized by reducing the amount of theoretical models necessary to master new topics to an absolute minimum.[9] Using real-world case studies as a means of generating interest and just-in-time teaching as a means of reducing distractions has been demonstrated to be a potent combination in the undergraduate classroom particularly in the thermal-fluid sciences realm.[8]

The end result of the careful process of selecting a structure and approach to the course appears in Table 3. This syllabus is the exact document the students received with the exception that the reading assignments and home study problem references have been removed for clarity. The syllabus highlights the case study approach to the course, the integrated nature of the material, and the technique of beginning as many lessons as possible with a question.

Table 3: ME311 Course Syllabus

BLOCK:	QUESTION	TOPICS	LSN	TITLE
	What are thermodynamics and fluid mechanics?	Introductory Concepts	1	Introduction to Thermal Fluids
Introductory Concepts	What tools do we need to discuss Thermal-Fluid systems?		2	Intro Concepts and Total Energy
			3	Ideal Gas Las, Internal Energy, Enthalpy, Specific Heat
		Progress Check	4	Writ I on Introductory Concepts / Intro to Reynolds Transport Theorem
BLOCK I: Helicopter Case Study	How to model Thrust?	Momentum Theory	5	Conservation of Mass / Momentum
	How does the aircraft start?	AH-64 Accumulator	6	Conservation of Energy for a Closed System / Moving Boundary Work
			7	Conservation of Energy for an Open System / Shaft Work (Double Period)
	How High?	Altimeters	8	Hydrostatic Pressure / Manometry
	How does it hold fuel ?	External Fuel Tanks	9	Hydrostatic Pressure on Submerged Plane Surface / Bouyancy / Problem Solving (Double Period)
	How fast?	Pitot-Static System	10	Bernoulli Equation
	Forces on Blades?	Blades / Airfoils	11	External Flow
	Application		12	Open Channel Lab (Staggered Schedule)
		Progress Check	13	Problem Solving (Double Period)
			14	WPR I
BLOCK II: Power Plant Case Study	What tools do we need to understand the powerplant?	Overview	15	Power Plant Overview, Steam Properties, Vapor Dome (Double Period)
		How well does powerplant operate?	16	Introduction to Losses
		Introductory Concepts	17	Increase in Entropy Principle
			18	Introduction to Cycles
		How well do components operate?	19	Steady Flow Devices
		Progress Check	20	EES Workshop
		Analysis Tool	21	Writ 2 / Intro to the Design
	How does the powerplant generate power?	Vapor Power Cycles	22	Vapor Power Cycles
			23	Improved Vapor Power Cycles
			24	Regenerative Vapor Power Cycles
			25	Steam Lab (Staggered Schedule)
			26	Powerplant Tour (Staggered Schedule)
	How does the water get to where it needs to go?	Pipe - Pump Systems	27	Intro to Pipe Flow
			28	Turbulent Pipe Flow and Major Losses
			29	Minor Losses
			30	Pipe Networks and Pumps
		Progress Check	31	Design IPR #1
			32	Problem Solving (Double Period)
			33	WPR 2
			34	Surface Tension, Capillary Action
Block III: Total Air Conditioning Case Study	How do we make the air in this building comfortable?	VCRC	35	Ideal Vapor Compression Refrigeration / Heat Pumps
			36	Actual VCRC and Refrigerant Properties
			37	Design IPR #2
		Psychrometrics	38	Psychrometrics
			39	Air-Conditioning Processes / Problem Solving (Double Period)
			40	Design Briefings (Staggered Schedule)

There are four areas of the course that deserve particular mention. During the semester, the students participated in two laboratory exercises, a tour of the West Point power plant, and a comprehensive Engineering Design Problem (EDP).

The first laboratory exercise, conducted on lesson 12 of 40 uses an open channel trainer, normally used by Civil Engineering majors in a Hydrology course. This exercise reinforced numerous concepts including conservation of mass, conservation of momentum, hydrostatics, control volume analysis, and manometry.

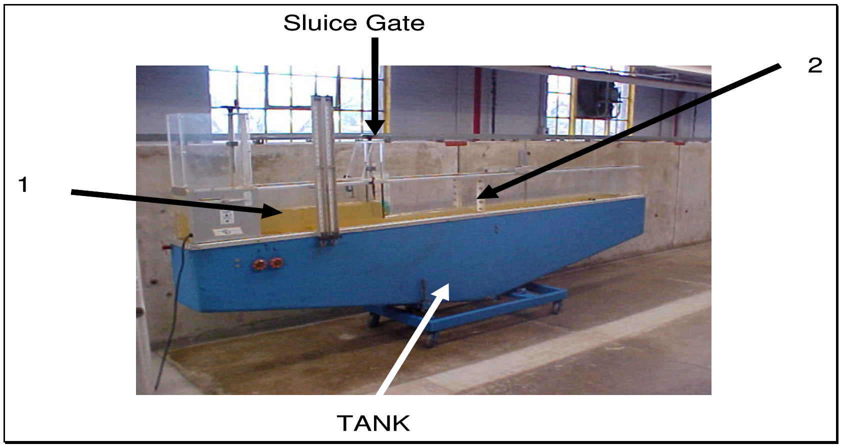

Figure 5: Open Channel Trainer

A picture of the device appears in Figure 5. The stated objectives of the laboratory were:

1. To determine the actual force on a sluice gate exposed to an open channel flow and compare it to the force calculated from a theoretical hydrostatic pressure distribution.
2. To determine the actual force on a sluice gate exposed to an open channel flow and compare it to the theoretical force calculated using the Conservation of Linear Momentum.

The laboratory was presented to the students as a request for assistance from a team of engineers in Iraq. The purpose was to use the open channel trainer to determine whether hydrostatic pressure or conservation of momentum would be the more accurate theory to predict the force on a sluice gate in a hydroelectric dam. Students measured actual pressures on a sluice gate in an open channel flow using manometers. They also calculated the theoretical force on the sluice gate using hydrostatic principles and conservation of momentum. A pre-laboratory exercise required students to conceptually determine the data they needed to acquire from the device in order to achieve the laboratory objectives. This introduced the concept of Design of Experiments into the curriculum before the students receive more formal training on the concept.

The second laboratory, conducted on lesson 25, was a steam power exercise that involved obtaining property data from two different steam turbines and a condenser. In addition, the students obtained power output data from a generator and a dynamometer to reinforce the principle that energy can be converted from one form, in this case thermal, to other forms such as mechanical or electrical. The stated objectives of this laboratory were:

1. Determine steam turbine performance by collecting and analyzing data during laboratory operation of two steam turbines.
2. Determine the effects of cooling water flow rate on the rate of heat transfer from steam flowing through a condenser, exit properties of steam from the condenser, and exit properties of cooling water from the condenser.
3. Describe the physical response of power plant generators and steam turbines when load demand changes due to daily societal activities.

This exercise had certain secondary learning objectives as well. First, in an attempt to reinforce the societal impact of engineering, students observed the effects on a steam turbine when the load demand changed by altering the number of light bulbs drawing power from the generator. In the laboratory report the students had to discuss the concepts of variable load demand by society and how plants adapt to and overcome this problem. Additionally, students determined the uncertainty of their data by conducting an uncertainty analysis on their calculations of the power from readings taken on the dynamometer.[10] The device displayed the RPM of the turbine output shaft and the torque. Based on these values, students calculated the power output and the relative uncertainty of that calculation, based on the uncertainty of the contributing data.

The students also had the opportunity to tour an actual cogeneration steam power plant. Fortunately, this building is adjacent to the department's academic building and is very convenient to use as an instructional aid. However, similar facilities exist in many communities and a trip could be coordinated. During the tour, students were exposed to actual steam turbines, boilers, pipe flow, pumps, cooling towers and various other devices that highlight the real-world nature of the Thermal-Fluid topics which they had already learned. This tour also was an introduction to the Engineering Design Problem (EDP) for the course.

The course EDP consists of an open-ended project that requires team effort. The scenario described destruction of many of the internal components of the existing power plant in a fictitious fire and extensive damage to the pipe system that supplies makeup water to the plant from a reservoir. Groups of three to four students had to develop a power plant design that satisfied a stated electrical power output requirement and a stated process heat requirement for the local West Point area. They also had to consider a pipe system to deliver the necessary makeup water and a nominal flow rate of additional water to the area, given a set of possible pipe and pump combinations. The students used the Engineering Equation Solver (EES) software from f-Chart software to conduct their analysis of the design. The emphasis of this project was on the business aspect of engineering as the students were required to conduct two in-progress reviews and one final brief as if they were briefing the head of the Military Academy's public works division. Their analysis included a 20-year life cycle discounted cash flow analysis of their proposed basic design, and an improved design that incorporated reheat or regenerative features into the plant.

Similar Course Offerings

There have been several undergraduate engineering curricula that have incorporated a combined course in Thermodynamics and Fluid Mechanics for a variety of reasons. Clemson University developed a similar course targeted to second semester sophomore Mechanical Engineering majors that sought to address several administration goals: create a curriculum that is more feasibly completed within four years and one that reflects the faculty's "sense of correctness" and ABET requirements.[5] The administration placed this Foundations of Thermal-Fluid Sciences course as a prerequisite for the full courses of Thermodynamics and Fluid Mechanics. Similarly, when the Mechanical Engineering department at Carnegie Mellon University (CMU) restructured their undergraduate curriculum, they chose to implement an integrated thermal-fluid science course.[6] West Point's specific implementation is remarkably similar to that of the Department of Mechanical Engineering, Aeronautical Engineering, and Mechanics at Rensselaer Polytechnic Institute. After their curriculum restructuring, they chose to implement two Thermal-Fluid sciences courses that focus on physical intuition as well as streamlining the course offerings.[7] The only large variation between their implementation and West Point's presentation is that the West Point faculty chose not to include topics in heat transfer, which is a required separate course. One of the stated objectives of this course was to prepare students for the FE exam, and several other programs have adopted this course format as a means to this end particularly for non-mechanical engineering majors.[11]

Course Textbooks

Finding a textbook that supports the goal of an integrated study of Thermodynamics and Fluid Mechanics was a challenge. A development team explored several options that would best support the course. The major considerations were integration of the material, content, and readability.

The textbook closest to the organization and integration necessary was Introduction to Thermal Sciences by Schmidt, Henderson, and Wolgemuth, but this text had not been updated since 1993. Its disadvantages included black and white text and a lack of good examples of real world applications. The other three textbooks examined moved towards integration in varying degrees, but were generally organized by topics in Thermodynamics first followed by topics in Fluid Mechanics. Introduction to Thermal and Fluid Engineering by Kaminski and Jensen and Introduction to Thermal Systems Engineering by Moran, Shapiro, Munson, and Dewitt were not as comprehensive in the area of fluid mechanics and would have required an extensive amount of supplemental material with several topics available only on CD or on a website.

Thermal-Fluid Sciences by Çengel and Turner was chosen as the best fit for the course of the options available. Although not providing as much of an integrated approach as desired, the textbook required the least amount of supplemental material and included the Engineer Equation Solver software with an Appendix in the text on how to use it. The text has strong online support and much of the nomenclature and notation match that in the Fundamentals of Engineering Reference Handbook.[12] The text is easy to read with colored text and many real world examples and was already being used in the department for ME350, Introduction to Thermal Systems with Army Applications, for the non-engineering majors. Therefore, the text would provide more seamless transitions for Instructors moving between the two courses.

The use of the case study approach forced students to skip around to different chapters in the Çengel and Turner text and caused some confusion among the students. For example, during the helicopter case study, the seven lessons had reading material from six different chapters. In addition, the textbook did not stay consistent in presenting the sign convention of the heat transfer and work terms in the use of the conservation of energy principle. The text initially used the heat in positive and work in negative convention when introducing the conservation of energy, but disregarded that sign convention when introducing power and refrigeration cycles in the governing equations and in example problems in the text. This caused some confusion among the students when using the conservation of energy equations to analyze cycles and components in those cycles.[13]

The lack of an integrated approach to the textbook made it more challenging to develop the material in an integrated fashion in class. For example, for a lesson on the conservation of energy for an open system, the integrated approach presents the opportunity to use the conservation of energy principle to derive the 1st Law of Thermodynamics, show the derivation of the mechanical-focused conservation of energy used in fluid mechanics, and with additional assumptions derive the Bernoulli equation. The text required reading assignments from three different chapters for this one lesson.

Some topics were not covered in enough detail in the text and required supplemental information. During lessons on vapor power cycles, the text included neither detailed information on regeneration, nor any details on open and closed feedwater heaters. The text also did not cover cogeneration or discuss the utilization factor as a measure of performance for vapor power cycles. Other topics that the text did not present in enough detail for course lesson objectives were sections on pumps, pump selection, and pump performance including cavitation.

The Fundamentals of Engineering Reference Handbook was used throughout the course in addition to the course text. Key equations from the text were cross referenced with the similar equations in the fluid mechanics, thermodynamics, and mechanical engineering sections of the FE Reference Handbook during course lectures. The handbook was allowed as an authorized reference on all quizzes and tests. Use of the FE Reference Handbook was emphasized throughout the course in order to familiarize the students with the organization and nomenclature used in the handbook and to increase student comfort with this reference in preparation for taking the required FE exam in the future.

Conclusions:

At the end of each semester West Point, like many colleges and universities, conducts a comprehensive, online feedback program aimed at improving the courses and programs. In open-ended feedback questions administered after course completion, students were asked what they particularly liked and disliked about the course. A strong majority liked the text book chosen specifically for the sample problems and for ease of reading despite the lack of continuity in the reading assignments. This indicates that the Çengel and Turner text was well regarded by students mainly for the reasons for which the book was chosen in the first place: readability and real world problems.

Regarding the case study approach, the majority of the students commented favorably on the case study approach overall and / or singled out an individual topic that interested them. The case study approach was an overwhelming success with the majority of the feedback being favorable and remarkably few negative responses. The just-in-time teaching technique was found to be seamless in its application with some favorable feedback on the flow and structure of the course.

A common theme in the feedback was an appreciation for “hands on application”. The power plant tour, the open channel laboratory, steam laboratory and a pipe friction demonstration were mentioned specifically as positive events that allowed students to observe the theories presented in class.

The engineering design project (EDP), in which the West Point power plant had to be redesigned, received considerable praise for tying together the bulk of the material in the course. Both formal and anecdotal feedback point to the fact that many students felt the EDP showed them how a majority of the course topics related to real-world problems and applications. However, the EDP also received a large majority of the dislike responses in large part because of the scope and complexity of the project. Therefore, it is clear that a better balance must be struck between creating an inclusive problem and overloading the students with work.

The students were also asked to rank the validity of several statements using a one to five scale with one being strongly disagree and five being strongly agree. The ME311 course compared favorably to the Mechanical Engineering division, the Department of Civil and Mechanical Engineering, and the Academy as a whole. One question asked, "My motivation to learn and to continue learning has increased because of this course." The course average was 4.29 out of 5 compared to an average response of 4.02 for all of the other courses at the academy. Another question asked, "In this course, my critical thinking ability increased." The course average for this question was 4.5 out of 5 compared to 4.1 for the academy as a whole. Both of these questions showed that students valued the approach used in the course and saw that the method enhanced their ability and desire to develop as engineers.

Recommendations:

As with any course offered for the first time, student feedback and instructor after action reviews revealed several areas that can be improved upon. Regarding the case study approach, this will continue to be a feature of the course and may be incorporated into other courses as well. Often in a class, many questions and discussions arose from the students about the case study or a similar application. By incorporating those discussions, the case study can be further enhanced in future course offerings. In addition, over time more information can be obtained about the case studies to increase the realism and applicability of the case study examples and problems. Overall, this was definitely a positive feature of this course offering and approach.

A major recommendation for future semesters includes the addition of a supplemental text to cover regenerative vapor power cycles as well as cogeneration. As previously mentioned, this was the one area not covered well in the Çengel and Turner textbook. Working with the publisher, the course will use a custom book with one chapter from the Çengel and Boles Thermodynamics: An Engineering Approach text to augment the existing text. Ideally, a completely custom text that integrates the topics in the course should be used. Such a text would not feature separate Thermodynamics and Fluid Mechanics sections. It would also address the topics on a more fundamental level and address the fact that both disciplines are essentially different ways to analyze energy and losses. Furthermore, a custom text that utilized a case study approach to developing the theory or the actual case studies used for ME311 would greatly enhance the course.

Another recommendation is to continue to use the Fundamentals of Engineering Reference Manual as a supplemental text for the course. The opportunity to view and use this reference tool early in students' academic careers is an excellent way to familiarize them with the layout and notation used in the manual.

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