SYSTEMATIC THERMAL SCIENCE COURSE DEVELOPMENT AT THE UNITED STATES MILITARY ACADEMY

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Abstract

The mission of the United States Military Academy (USMA) is "To educate, train, and inspire the Corps of Cadets so that each graduate is a commissioned leader of character committed to the values of Duty, Honor, Country; professional growth throughout a career as an officer in the United States Army; and a lifetime of selfless service to the nation."[1] In order to accomplish this mission, USMA cadets endure 47 months of demanding training, which includes eight academic semesters. Each cadet receives a Bachelor of Science degree, upon graduation, and is commissioned as an officer in the United States Army.

Currently, each graduate, regardless of major, is required to take a minimum of five engineering courses. These five-course engineering sequences are offered in seven disciplines; Computer Science and Civil, Electrical, Environmental, Mechanical, Nuclear and Systems Engineering. The five-course sequence is being restructured for the class of 2005. The resulting sequence will include an information technology course, an integrative experience, and a new three-course engineering sequence that progresses from predominantly science to mostly design content. The new three-course engineering sequences will be offered in the same seven disciplines. This change to the academic program has driven the requirement for the development of a number of new courses.

The new mechanical engineering sequence includes an introductory thermal science course. This course, which introduces cadets to the fundamentals of thermodynamics, fluid mechanics, and heat transfer will be taught to non-engineering majors. This atypical group of students forces the development team to construct a completely new course. The engineering design process is used as a facility to drive the development of this course from problem definition, through design and analysis, to implementation. Unique aspects of this course include the identification of customer (Army) requirements, class size, and composition. Since all cadets enter the Army after graduation, we consider the Army our main constituent. Thus, the course is developed by focusing on typical Army thermal systems. Class size is limited to 18 students, in this case, all non-engineering majors. This class make-up has prompted a very active learning

environment with multiple demonstrations, physical models, and laboratories. This paper presents a detailed discussion of how this thermal science course was developed at USMA.

The West Point Environment

The United States Military Academy (USMA), located in West Point, New York, is one of the premier commissioning sources of officers in the US Army. The Military Academy admits about 1,300 students each year from over 10,000 applicants. Each applicant's file is screened for academic, athletic and extracurricular achievement. Furthermore, each candidate must pass a physical fitness test and examination. Finally they must receive a nomination from one of their state's congressmen prior to admission. This stringent admission process is imposed to admit only those applicants who possess the potential to become outstanding officers in the Army. After gaining admission and completing an arduous summer of military training they are considered part of the Corps of Cadets (student body), a group of approximately 4,000 cadets.

Academic Program

USMA offers a diverse variety of disciplines in 13 academic departments. Twenty-four majors and 17 fields of study are offered in mathematics, science and engineering disciplines, while 44 majors and 52 fields of study are offered in the humanities and public affairs disciplines.[2] In order to function effectively as an officer in unfamiliar situations, one must possess a breadth of knowledge in many disciplines. To meet this need, each cadet must complete a core curriculum in their first two years at West Point. This core curriculum is shown below in Table 1.

Table 1: USMA Core Curriculum

SUBJECT	NUMBER OF SEMESTERS	SUBJECT	NUMBER OF SEMESTERS
Plebe Year (Freshman)		**Yearling Year (Sophomore)**	
Chemistry	2	Economics	1
Computer Science	1	Foreign Language	2
English	2	Mathematics	2
History	2	Philosophy	1
Leadership	1	Physical Geography	1
Mathematics	2	Physics	2
		Political Science	1
Cow Year (Junior)		**Firstie Year (Senior)**	
English	1	Law	1
Leadership	1		
International Relations	1		
Military History	2		

Currently, in addition to the core curriculum, every cadet must take a minimum of five engineering courses. Engineering students satisfy this requirement in their specific engineering discipline. All other students, however, select their five-course sequence in the first semester of their sophomore year, at the same time they select their major. The seven sequences are offered in the following disciplines: Civil Engineering, Computer Science, Electrical Engineering, Environmental Engineering, Mechanical Engineering, Nuclear Engineering, and Systems Engineering.

The five-course sequence offered in Mechanical Engineering includes Statics and Dynamics, Thermodynamics, Mechanics of Materials, and two courses in Mechanical Engineering Design. As such, mechanical engineering instructors are challenged to teach these courses to students majoring in a variety of areas like history, political science, language, and management. Furthermore, mechanical engineering majors take each of these courses with non-engineering majors. As a result, most course content is dictated by Accreditation Board for Engineering and Technology (ABET) requirements, some of which is not as applicable to non-engineering majors. This places an additional constraint on the curriculum. Offering some courses, specifically, to non-engineering majors would allow tailoring of course content to better meet student needs.

Faculty

The Mechanical Engineering Division has a unique mix of faculty that executes this academic program. The faculty is composed of four permanent military members, 18 rotating military members, and four civilians.[3] The four civilian faculty members in the department bring an indispensable component of academic experience, and are an excellent source of pedagogical advice for the junior faculty. The four permanent military faculty members within the department all hold a doctorate in a relevant discipline and are charged with maintaining continuity of the academic program. This continuity is essential because the majority of the faculty rotate back to an operational assignment in the Army after three years at the Academy. These rotating military faculty generally attend graduate school at a civilian university after completing seven to nine years of successful military service. While at graduate school the rotating faculty pursue a Master of Science in Mechanical Engineering and then proceed to USMA where they participate in a six-week summer teaching workshop preparing them for a three-year tour as an instructor. Although these junior officers may not have a wealth of academic experience, they are essential to cadet development because they are excellent role models of successful Army officers.

Classroom Environment

Motivating cadets' learning in engineering education is always critical, however this becomes even more important when teaching engineering courses to non-engineering majors. In order to influence these students we develop an active learning environment. Class sizes are constrained to no more than 18 students. This allows for more instructor-student interaction. Each class of students is organized into three or four person groups. This helps the cadets learn by helping each other, and also forces them to work as a member of a team, an ability required of Army officers. The active learning environment involves many hands-on applications of engineering. Many physical models, training aids and laboratories are used to enhance the active learning atmosphere.[4]

Why Change the Curriculum?

In 1999 a USMA Strategic Assessment Working Group was developed. This panel included many senior military officers, retired officers and accomplished scholars. Formation of this group was in response to a technologically changing Army and a poorly defined military threat. These factors force our graduates to employ advanced systems in unfamiliar political and cultural environments. These changes in our military prompted a critical, external assessment of the Academy's academic program.

Results from the Strategic Assessment Working Group were forwarded to and compiled by the Office of the Dean. The Dean's staff conducted a study that generated various courses of action for academic change. These recommendations ran the gamut from no change to complete omission of the engineering sequences. The different options were analyzed by nine academic goal teams to determine which ones supported each academic goal. The most appealing option was to reduce the five-course engineering sequence to a three-course sequence. The void from the two deleted engineering courses would be filled by an information technology course and an integrative experience. The information technology course addresses the advanced technology in the Army. The integrative experience is a culminating exercise, requiring cadets to combine components of their broad academic experience into one academic endeavor. This course addresses the complex, unfamiliar environments in which officers must operate.

The new three-course engineering sequences will be offered in the same disciplines that offer the current five-course sequences. In an effort to standardize these sequences the Strategic Assessment Working Group crafted an engineering and technology goal, a list of outcomes, a learning model and a common design process.[5]

Engineering and Technology Goal

The revised Engineering and Technology Goal is for graduates "To anticipate and respond effectively to the uncertainties of a changing technological, social, political and economic world." Inherent in this goal is a graduate's ability to effectively solve complex problems. This is particularly important because a successful Army officer must be a good problem-solver. Engineering education is important because it teaches students a systematic approach to solving complex problems.

Engineering and Technology Outcomes

Meeting this goal involves expertise in a number of areas. In order to add clarity to the goal, Engineering and Technology Outcomes were developed. These outcomes describe what a graduate will be able to do upon completion of the program. The Engineering and Technology Outcomes are listed below:

1. Identify needs that can be fulfilled via engineered solutions.
2. Define a complex problem, accounting for technological, political, social and economic dimensions.

3. Determine what information is required to solve the problem and either acquire the information from appropriate sources or make reasonable assumptions.
4. Apply an engineering design process to develop effective solutions.
5. Apply mathematics, science and engineering to model and analyze a physical system or process.
6. Work effectively on a team to solve a problem.
7. Communicate, plan the implementation and assess the effectiveness of an engineered solution.
8. Demonstrate technical proficiency in an engineering discipline that is relevant to the needs of the Army.

The Learning Model

A common Learning Model was adopted for each engineering sequence to add structure to the cadet's academic experience. Each cadet still takes a core curriculum during the first two years at the Academy. A portion of this curriculum gives them the math and science foundation required for success in each engineering sequence. All seven three-course sequences follow an integrated progression from predominantly engineering science to mostly engineering design. A common design process is introduced early in each sequence and is used as the framework for all engineering science and design. This design process is shown below in Figure 1. Each three-course sequence provides engineering science unique to that discipline and uses the common design process to integrate the topics. The final course is a culminating design experience, which provides cadets the opportunity to apply concepts learned in previous courses.

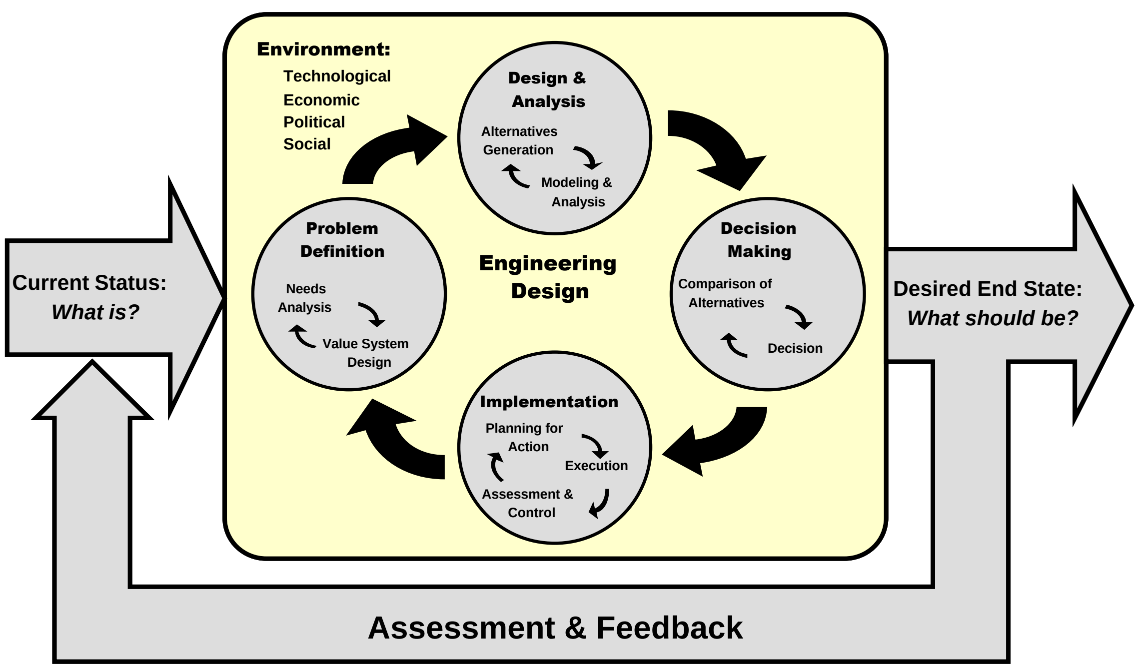

Figure 1: The Common Engineering Design Process

This common process is incorporated to ensure all students learn engineering design and develop a common problem-solving thought process. All seven disciplines will apply the model differently, by focusing on each phase to a varying degree.

Mechanical Engineering's Three-Course Sequence

The Mechanical Engineering Division used a design process to determine the composition of the new three-course sequence. Numerous options were discussed including a mixture of existing and new courses. The existing courses include Statics and Dynamics, Thermodynamics, Fluid Mechanics, and Engineering Design. The new courses proposed were Statics and Strengths (CE300), Thermal Sciences (ME350), and Mechanical Engineering Design (ME450). Eleven different combinations of these courses were considered. Some of these options included engineering and non-engineering students in the same classes, as is currently true, while others separated them. After careful consideration, we selected an option that included the three new courses that only non-engineering majors would take. By selecting this option we had the advantage of being the able to tailor each course's content to cadet needs without being constrained by ABET requirements. It also allowed us to design the courses with the depth and breadth required to meet the engineering and technology goal. The first course EM300, includes statics, fundamentals of stress and strain, shear moment diagrams, bending, torsion and an introduction to the engineering design process. ME350, the second course in the Mechanical Engineering Sequence, includes concepts from classical thermodynamics, fluid mechanics and heat transfer. The final course, ME450, incorporates the previous material in an engineering design process. In this course cadets are required to design and build two devices, in a formal group, using the concepts mastered in EM300 and ME350.

Thermal Science Course Development

Developing a new course is an extremely complex task, one that lends itself to a systematic problem solving process. USMA's thermal science course development team consists of four rotating military faculty members and one civilian faculty member. Currently, two of these members teach thermodynamics, two teach fluid mechanics and one teaches heat transfer. These members include course directors from each of these courses. We chose to use the common engineering design process to design the Academy's new thermal science course. We adapted the design process to meet our course development needs. Figure 2 illustrates the common design process as it was used in course development.

Problem Definition

We initiated the course development process by defining the problem. This phase started with the work completed by the Engineering and Technology Goal Team, one of the nine goal teams that analyzed each course of action proposed by the Dean's staff study. Results of the Engineering and Technology Goal Team's work include an updated Engineering and Technology Goal, objectives and a revised learning model. These tools gave us a focus for course development. ME350, being the second course in the sequence, will be composed mostly of engineering science content. We will only refer to the design process to give cadets a picture of where thermal system analysis fits into the overall process. We need to present a systematic problem solving process early in the course and reinforce it through repetitive practice. Finally, the cadets need to work as a team to solve these complex engineering problems.

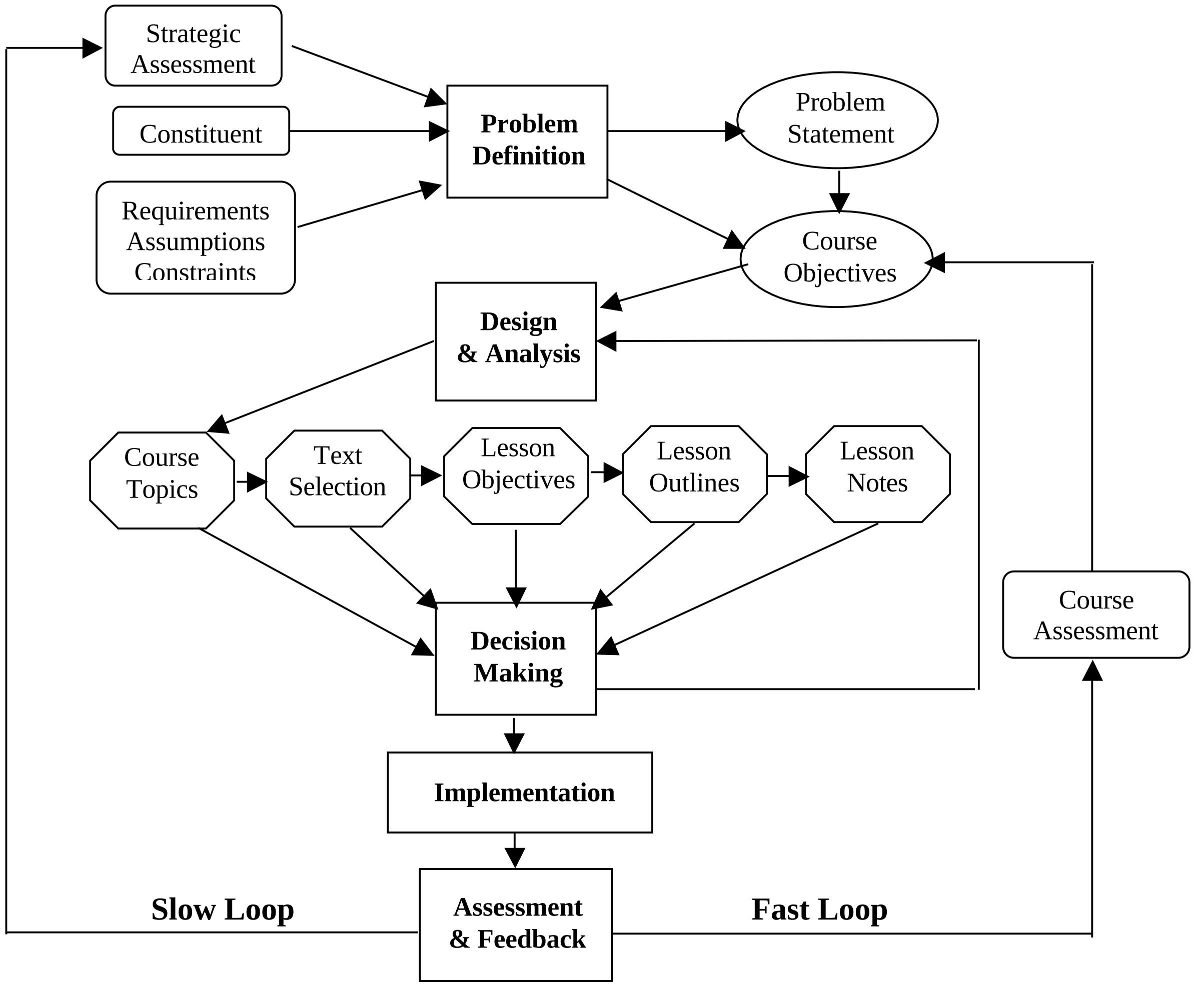

Figure 2: Course Development Process

Constituent needs were analyzed in an effort to properly define the problem. We found two primary customers, the first being the Army. We chose the Army because all cadets will be commissioned as officers upon graduation. This course is part of their preparation as future Army officers. The Engineering and Technology Objectives specifically list a need to demonstrate technical proficiency relevant to the Army. As such, our analysis of thermal systems should include equipment present in the Army. We listed Army thermal systems to better define the scope of our course. This list includes compression-ignition, spark-ignition and gas turbine engines, pipe flow, pumps and drag.

The second customer was the cadet. By selecting a three-course sequence made of non-existing courses, we narrowed the composition of students to all non-engineering majors. This does not indicate that the students are less capable. It does indicate, however, that they will be less interested in engineering topics than engineering students. In order to motivate learning we need to find a common interest among these students. The common interest is obviously Army applications. To that end, every lesson must be tied to some Army application and the cadets must be constantly reminded of this linkage. A great way to accomplish this is by posting a course overview in the classroom. The overview is then referenced at the start of every lesson. This technique also appeals to global learners who need to be reminded where all the lessons are leading.

The final input to the problem definition are the requirements, assumptions and constraints. Primary requirements include sufficient coverage of thermal systems to allow cadets to analyze them, application of previously learned math and science skills, and the use of physical models. These physical models, laboratories and training aids, enhance the hands-on nature of the course and reinforce theoretical content.[6] The major constraint is the fact that most instructors will have limited academic experience. To prevent this inexperience from being detrimental, the course must be well structured and notes must be meticulously prepared in advance.

Problem Statement

The problem definition phase resulted in a problem statement and course objectives. The problem statement is to "Design a 3.0 credit hour course introducing cadets to the fundamental concepts necessary to analyze thermal systems present in the Army."

Course Objectives

Course objectives were carefully drafted with input from the entire problem definition phase. The objectives are things the cadets should be able to do upon successful completion of the course. They are not a task list for instructors to complete. The objectives became the reference used for all subsequent development issues. The ME350 Course Objectives are:

1. Define, determine and relate physical and thermal properties.
2. Apply a systematic thought process to solve engineering problems.
3. Analyze thermal systems by applying conservation of mass, momentum and energy.
4. Apply the knowledge gained in ME350 to Army problems.
5. Solve problems as a member of a team.

Design & Analysis

At this point the problem, developing a new course in this situation, was adequately defined and we could proceed to the next phase of the process. The design and analysis phase here is an iterative process. Once a course of action is selected in a particular area, every other area must be addressed for effects of the decision. During this iterative process the course objectives remained the guide for all decisions.

Course Topics

The first task in this stage was to list the course topics required to meet course objectives. The topics are not all explicitly listed in the objectives. Many of them are building blocks leading toward accomplishment of the course objectives. The topic list changed many times during the design process because various decisions forced the inclusion or omission of certain topics. The course topic list is:

1. Introduction to thermal sciences.
2. Systematic problem solving process and analysis methods.
3. Thermodynamic and physical properties.
4. Equation of state.
5. Conservation of mass, momentum and energy.
6. Hydrostatics.
7. Engineering devices including: turbines, compressors, nozzles, diffusers, pipes, pumps, piston-cylinders and heat exchangers.
8. Second Law analysis to include cycle and isentropic efficiencies.
9. Applications of thermal systems.

These course topics are focused on the material required to analyze Army applications of thermal systems. Properties and equations of state were required because thermal analysis requires an understanding of properties and the ability to relate them. We wanted to develop the conservation equations early and in an integrated manner. The conservation equation derivations are presented to show that thermodynamics, fluid mechanics and heat transfer are all interrelated, and system analysis is simply an application of these equations. A wind tunnel laboratory is inserted here to reinforce Bernoulli's equation. Much of the course is then spent analyzing engineering devices using the conservation equations, because these devices are the building blocks for cycles. The second law is used to determine process direction and to compare the relative merit of components and entire cycles.

The last portion of the course is devoted to Army applications. The Otto, Diesel, and Brayton cycles are described and analyzed. Actual spark-ignition, compression ignition and gas turbine engines are studied. Numerous physical models are used to generate interest in these applications. These models include actual jeep, tank and helicopter engines, turbine and compressor blades and pumps. These topics are then reinforced in laboratories. An internal combustion engine Cooperative Fuel Research laboratory is used to allow cadets the opportunity to analyze the performance of a spark ignition engine by varying spark timing angle, compression ratio and fuel octane. A gas turbine laboratory is used to solidify the cadet's ability to analyze a cycle by applying the first law and isentropic efficiencies. Finally, drag is studied to allow cadets an opportunity to synthesize all course topics. For example, the cadets will be tasked to size an engine for a vehicle required to maintain certain cruising speed accounting for drag.

Text Selection

Selecting the right textbook is critical to the success of a course. Students should be responsible for their own learning, but they can only be held accountable if they have a reference from which to learn on their own. Introductory engineering texts must be easily read to encourage study out of class. A thermal science text incorporates material from thermodynamics, fluid mechanics and heat transfer. These subjects use a great number of symbols. The entire book should be consistent with nomenclature to prevent confusion. A thermal science course should present all material in an integrated manner to give the students the perception that all topics are interrelated. Otherwise the course will seem to be three subjects shoved into one course. Finally, the text should adequately cover all concepts addressed in the course so it will serve as a valuable reference during the course and after completion. The ME350 development team deliberated the relative importance of these and other criteria for text selection. We weighted each quality according to its relative importance. Table 2 is our final text selection matrix with weighted averages of our assessment.

Table 2: Text Selection Matrix

Evaluation Criteria	Weight	Text A	Text B	Text C
Readability	2	5.8	7.4	7
Integration of Material	3	13.2	4.8	8.1
Topic Coverage	3	6.3	14.1	4.2
Accuracy	3	11.1	10.2	10.2
Consistency	2	7.8	6	7.8
Quality of Problems	1	3.6	4.2	2.6
Sequence of Presentation	1	3.2	3	3.1
Total		51	49.7	43

All team members were instructed to rate each prospective text on a scale of one to five, five being the best. Team members were prohibited from collaborating during this process to avoid biasing each person's opinion. The selection matrix allowed us to eliminate Text C as an option. We then discussed how each remaining text would support the course objectives. Each text had some benefits and deficiencies. Text A integrated the conservation equations well but included very little coverage of Otto, Diesel and Brayton cycles. Text B developed the conservation equations separately in fluids and thermodynamics sections, but covered all course topics exceptionally well.

Next we listed courses of action that would mitigate these problems. We considered taking material from various books and constructing our own text, however nomenclature problems would surely arise. We also considered augmenting the text with our own notes, however these notes would not serve as a good reference after completion of the course. Our last option was to use a reference sheet to integrate the conservation equations. The list below summarizes all of these options.

1. Text A alone.
2. Text A with notes.
3. Text A augmented with other texts.
4. Text B alone.
5. Text B with notes.
6. Text B with reference sheet.

We analyzed each option's ability to support the course objectives and determined that option 6 was our best course of action. We also checked to ensure that this option would support the course topics list, which it did.

Lesson Objectives

Once a text was selected, we started dividing the topics into lessons. This involved sequencing the topics in a logical progression and breaking the concepts into manageable, coherent groups that fit into a single lesson. Finally, we listed lesson objectives that support each course topic. These lesson objectives are the tasks that a cadet should be able to complete at the end of a given lesson. The list of lesson objectives was scrutinized to ensure they supported the course objectives. We then listed the reading assignment that supports each lesson objective. After careful inspection of the reading assignments, we changed the order of some topics, added some topics that we overlooked and deleted some material that was unnecessary. The lesson objectives were consolidated in a course syllabus. The syllabus lists the lesson topics, lesson objectives and associated reading assignments. The final course syllabus may be seen in Appendix A.

Lesson Outlines

We developed lesson outlines as one final check to ensure that no concepts were overlooked, and that all subjects will be presented in a common sense sequence. The lesson outline is a link between the syllabus and the lesson notes. The lesson outlines were compiled in a matrix, which allowed us to easily see how the material was layered into the course. This matrix consisted of one column for each of the 40 lessons, followed by the sequence of concepts presented in each lesson. We made some simplifications, allowing us to omit some unnecessary material. We shifted some material to places where they fit more logically and added some material required to properly develop other concepts. Finally, we ensured that the outlines still supported the course objectives, topics and lesson objectives.

Lesson Notes

The final stage of the design and analysis was to write the lesson notes for each lesson. The lesson notes are a great tool that add structure and continuity to the course. Continuity is a requirement due to the constant turnover of rotating faculty. The structure gained from lesson notes assists inexperienced faculty in becoming effective teachers. The lesson notes show a logical presentation of the material for a particular lesson. These notes could be transcribed directly onto chalkboards in the room and serve as an effective presentation. Remarks are included in the notes giving ideas for clear explanation, use of training aids, and references to the text. When the course is being taught, these lesson notes will be discussed in a weekly coordination meeting held by the course director and attended by all instructors.

Implementation

ME350 will be taught for the first time in the spring of 2004, to the Class of 2005. Inevitably, there will be a number of issues that we overlooked while constructing the course. The Department of Civil and Mechanical Engineering has an effective assessment process that will rectify these problems. This assessment process is used in each of our courses. Simple problems are corrected in weekly lesson conferences held before the material is even taught. Some issues are discovered while teaching a particular topic. These issues may involve the sequence or manner with which material is presented. Some lessons may have too much material, while others not enough. The course director maintains a record that includes all the issues that arise throughout the semester. This becomes part of his course director's notebook. Additionally, instructors offer feedback to the course director and periodically solicit feedback from their students. This feedback includes a daily time survey, which students fill out anonymously, recording the number of minutes each cadet spends preparing for a lesson or completing the requirements of the last lesson. The feedback is compiled and inserted into the course director's notebook. Finally, each cadet fills out a course critique at the end of the semester. In this critique cadets anonymously rate their ability to complete the course objectives as well as offer suggestions to improve the course from their perspective. All the feedback is analyzed by the course director who generates a course assessment report. The report is briefed to the Mechanical Engineering Division Director in the presence of all instructors and any other interested parties. During this briefing, changes are recommended to improve the course based on the feedback. These actions are conducted annually and comprise the "fast loop" of the assessment process. (See Figure 2).

Overall Academic Program Objectives take longer to evaluate because these are things that graduates should be able to do three to five years after graduation. Feedback related to these objectives is relatively easy for us to obtain because our graduates are still in the Army after four years. Four years after graduation surveys are sent to all graduates and their immediate supervisors. The surveys ask a number of questions related to the program objectives. Once these surveys are returned, the data is compiled and analyzed by the nine academic goal teams. This assessment process, the "slow loop", obviously takes much longer to evaluate the effects of a change. In this case the Strategic Assessment Working Group, formed in 1999, was the first step leading to the academic program revision from a five to a three course engineering sequence. The first feedback relating the effects of this change will not be collected until 2009, a full 10 years after the process was initiated.

The Future of ME350 at USMA

The iterative assessment and design process will continue to improve ME350 through the annual course assessment. Course assessments will also be conducted annually for EM300 and ME450, the first and third courses in the three-course sequence. Additionally, the mechanical engineering three-course sequence will be assessed annually. These assessments comprise the fast loop of the design process. The result of this assessment and refinement process will be three courses that effectively introduce students to mechanical engineering. The fact that these courses are allowed to evolve without ABET constraints make them appealing models for introductory mechanical engineering courses. Since the development was not constrained we were able to omit and insert topics that allow for a logical, integrated presentation of thermal sciences. The assessment process will determine which of these decisions were appropriate. After two or three annual cycles, this course will be an excellent model of an introductory thermal science course for mechanical engineering majors at USMA and elsewhere.

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Appendix A: Course Syllabus

Lesson	Lesson Objectives	Assignment
TS-1 Introduction to Thermal Sciences	1. Explain course administrative policies. 2. Identify thermal systems. 3. Define closed system and control volume. 4. Explain a systematic problem solving process.	**Study: 1.1-1.4, 1.6, 1.9**
TS-2 Properties 1	1. Define thermodynamic and physical properties. 2. Define state and process. 3. Identify special processes. 4. Explain Temperature, Pressure, Density, Specific Gravity and Viscosity. 5. Relate properties using the ideal gas law.	**Study: 1.7, 2.1-2.2, 2.4, pg 46-47, 3.7-example 3.11, 9.4**
TS-3 Conservation of Mass	1. Develop the conservation of mass principle for closed system and control volume. 2. Apply the Reynolds Transport Theorem to develop conservation of mass for a control volume.	**Study: 1.10, 11.5**
TS-4 Conservation of Momentum	1. Develop the conservation of momentum principle for a closed system and control volume. 2. Solve problems using conservation of mass and momentum.	**Study: 11.6**
TS-5 Properties 2	1. Describe the forms of energy. 2. Define internal energy and enthalpy. 3. Determine changes in internal energy and enthalpy using specific heats.	**Study: 2.3, 3.9-3.11**
TS-6 Energy Transfer	1. Describe energy transfer through heat transfer, work and mass flow. 2. Describe the forms of work. 3. Develop expressions to solve for boundary and flow work. 4. Develop expressions for the energy transfer due to mass flow.	**Study: 4.1-4.2, 4.3.1-4.3.2, 4.5**
TS-7 Conservation of Energy	1. Develop conservation of energy statements for closed system and control volume. 2. Develop Bernoulli's equation.	**Study: 5.1-5.2, 11.4-pg470**
TS-8 Engineering Devices (Nozzles, Diffusers, Turbines and Compressors)	1. Describe the following steady-flow engineering devices and list their purposes: nozzle, diffuser, turbine, and compressor. 2. List applications of nozzles, diffusers, turbines, and compressors. 3. Apply the conservation of mass and conservation of energy (1^{st} Law of Thermodynamics) to solve problems.	**Study: 5.4-pg178**
TS-9 Review Class	1. Review lessons 1-8.	
TS-10 Exam 1	1. Review lessons 1-8.	

Lesson	Lesson Objectives	Assignment
TS-11 Hydrostatics 1	1. Distinguish between gage and absolute pressure. 2. Develop the hydrostatic pressure equation by applying Newton's 2d Law to a static fluid element. 3. Apply the hydrostatic pressure equation. 4. Apply Pascal's principle to solve problems involving hydraulics.	**Study: 2.5-2.6**
TS-12 Wind Tunnel Lab	1. Experimentally determine velocity in a fluid flow using a pitot-static tube. 2. Calculate the uncertainty in a variable.	**Study: 11.2-11.3** **Uncertainty Handout**
TS-13 Wind Tunnel Lab	1. Experimentally determine velocity in a fluid flow using a pitot-static tube. 2. Calculate the uncertainty in a variable.	**Study: 11.2-11.3** **Uncertainty Handout**
TS-14 Hydrostatics 2	1. Determine the magnitude, direction and location of hydrostatic forces on plane, submerged surfaces. 2. Solve rigid body static problems involving hydrostatic forces on plane submerged surfaces.	**Study: 10.1-10.2**
TS-15 Hydrostatics 3	1. Define and apply Archimedes' principle of buoyancy.	**Study: 10.4**
TS-16 Pipe Flow 1	1. Classify pipe flow as either laminar or turbulent. 2. Determine the friction factor for laminar pipe flow. 3. Apply the Darcy-Weisbach equation to calculate head loss for pipe flow. 4. Apply the energy equation to laminar pipe flow.	**Study: 12.1-12.3**
TS-17 Pipe Flow 2	1. Determine the friction factor for turbulent flow. 2. Apply the energy equation to turbulent pipe flow. 3. Determine pressure drop, flow rate in a pipe and pipe diameter necessary to obtain a desired flow rate.	**Study: 12.4**
TS-18 Pipe Flow 3	1. Apply the energy equation to pipe flow with minor losses.	**Study: 12.5**
TS-19 Pipe Flow 4	1. Determine system operating point with a pump.	**Study: 12.6 pgs 534-539**
TS-20 Pipe Flow 5	1. Analyze pipe flow with pipes in parallel.	**Study: 12.6 pgs 532-533**
TS-21 Exam 2	1. Review Lessons 11-20.	

Lesson	Lesson Objectives	Assignment
TS-22 First Law for a Cycle and Introduction to the 2^{nd} Law.	1. Describe: Thermal Reservoir, Sink, Source and Thermal Efficiency. 2. Apply the 1^{st} Law for a cycle. 3. Describe the Kelvin Planck Statement of the 2^{nd} Law. 4. Recognize the necessity of the 2^{nd} Law of Thermodynamics in determination of process direction.	**Study: 6.1-6.3**
TS-23 Entropy the Property and Entropy Change for a Pure Substance	1. Explain reversible and irreversible processes. 2. List irreversibilities. 3. Describe the Clausius inequality for a reversible cycle and process. 4. Describe Entropy. 5. Recognize the Gibbs relations and apply the expressions to calculate entropy change. 6. Determine entropy change for an ideal gas.	**Study: 6.7, 7.1, 7.7, 7.9**
TS-24 Entropy Generation	1. Calculate the entropy generation for closed systems and control volumes.	**Study: 7.2-7.4**
TS-25 Isentropic Efficiencies for Engineering Devices	1. Define and calculate isentropic efficiencies for steady flow devices. 2. Apply isentropic relations for an ideal gas.	**Study: 7.12**
TS-26 Introduction to Heat Transfer	1. Explain conduction heat transfer and Fourier's Law. 2. Explain convection heat transfer and Newton's law of cooling. 3. Analyze simple conduction using an electrical analog in cylindrical coordinates.	**Study: 14.1-14.4, 15.4**
TS-27 Convection Heat Transfer	1. Describe the velocity and thermal boundary layers. 2. Explain the physical significance of the Reynolds, Prandtl and Nusselt numbers. 3. Determine heat transfer coefficients for internal and external convection. 4. Analyze convection problems using Newton's law of cooling.	**Study: 17.1-17.4, 17.7**
TS-28 Heat Exchangers	1. Describe different heat exchanger arrangements. 2. Explain the concepts of overall heat transfer coefficient and heat capacity rate. 3. Apply the Log Mean Temperature Difference (LMTD) method to analyze heat exchangers.	**Study: 20.1-20.2, 20.4**
TS-29 Review Class	1. Review lessons 22-29.	
TS-30 Exam 3	1. Review lessons 22-29.	

Lesson	Lesson Objectives	Assignment
TS-31 Internal Combustion Engines 1	1. Identify basic components of a piston-cylinder engine. 2. Describe the four-stroke and two-stroke mechanical cycles. 3. Describe the compression ignition engine.	**Study: 8.4–8.6**
TS-32 Internal Combustion Engines 2	1. Apply the cold-air-standard assumptions to ideal spark ignition and compression ignition engines. 2. Describe the cold air-standard Otto and Diesel cycles. 3. For the Otto cycle, describe the following performance parameters: compression ratio, and thermal efficiency. 4. For the Diesel cycle, describe the following performance parameters: compression ratio, cut-off ratio, and thermal efficiency. 5. Solve Otto and Diesel cycle problems.	**Study: 8.3**
TS-33 Internal Combustion Engine Cooperative Fuel Research (CFR) Lab	1. Analyze tests on a spark ignition engine to determine the effects of spark timing, compression ratio, and fuels on engine performance.	**Study: Prelab**
TS-34 Gas Turbines 1	1. Describe how an actual gas turbine engine operates and list its components. 2. Describe the cold air-standard Brayton cycle. 3. Describe regeneration and regenerator effectiveness. 4. Describe the following performance parameters: pressure ratio, back work ratio, and thermal efficiency. 5. Solve a gas turbine problem with regeneration.	**Study: 8.7-8.8**
TS-35 Gas Turbines 2	1. Describe the ideal jet propulsion cycle. 2. List and describe methods to increase thrust force. 3. Describe the following performance parameters: propulsive power and propulsive efficiency. 4. Solve jet propulsion cycle problems.	**Study: Prelab**
TS-36, 37 Gas Turbine Lab Bldg. 609, between Lincoln Hall and Kosciusko's Statue	1. Conduct tests on a gas turbine engine to determine engine performance characteristics.	**Study:**
TS-38 Drag	1. Define drag and the drag coefficient, C_D. 2. Describe the effects of streamlining on overall drag force.	**Study: 13.1-13.3**
TS-39 Drag	1. Calculate drag forces on various 2D and 3D bodies. 2. Calculate terminal velocity for objects in free fall.	**Study: 13.4**
TS-40 Semester Review Class	1. Review lessons 31-39.	**Study:**

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