The Evolution of an Energy Conversion Course at The United States Military Academy

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Abstract

Over the past several years, an energy conversion course offered by the Mechanical Engineering Program at West Point has evolved into a cohesive series of lessons addressing three general topical areas: advanced thermodynamics, advanced mechanical system analysis, and direct energy conversion systems. Mechanical engineering majors enroll in Energy Conversion Systems (ME 472) during the fall semester of their senior year as an advanced elective. ME 472 builds directly on the material covered in Thermodynamics (EM 301) taken during the student's junior year. In the first segment of ME 472, the students study advanced thermodynamic topics including exergy and combustion analyses. The students then analyze various mechanical systems including refrigeration systems, internal combustion engines, boilers, and fossil fuel-fired steam and gas turbine combined power plants. Exergetic efficiencies of various equipment and systems are determined. The final portion of the course covers direct energy conversion technology, including fuel cells, photovoltaics, thermoelectricity, thermionics, and magnetohydrodynamics. Supplemental lessons on energy storage, semi-conductors, and nonreactive energy sources (such as solar collectors, wind turbines, and hydroelectric plants) are included here. This paper discusses the evolution of ME 472 over the past several years and explains the motivations for the course's progress.

I. Introduction

The United States Military Academy (USMA) at West Point is the oldest engineering institution in the nation, having taught engineering science and design to students of military art since 1802. The Academy's overarching general educational goal is "To enable its graduates to anticipate and to respond effectively to the uncertainties of a changing technological, social, political and economic world".[1] The mission of the 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]

All thirteen academic departments, which offer over sixty majors, strive to meet the academy's goal and mission. While pursuing a four-year college degree, the students that attend the academy are also training to serve as officers in the United States Army and are therefore known as cadets. The complete student body is referred to as the Corps of Cadets and includes representation from every state in the nation as well as numerous foreign countries.

West Point's Department of Civil and Mechanical Engineering offers an Accreditation Board for Engineering and Technology (ABET) accredited degree in mechanical engineering (ME). Cadets enrolled in ME must successfully complete a course of study very similar to that required by their peers at civilian institutions. Each year, approximately 75 cadets select mechanical engineering as a major. All ME majors enroll in Thermodynamics (EM 301) during their junior year, while approximately half enroll in Energy Conversion Systems (ME 472) during the fall semester of their senior year.

While most institutions do not possess the same mission and goal as the United States Military Academy, most do share the same desire and requirement to improve curriculum structure, integration, and assessment. Accordingly, the ABET EC2000 Criteria for curricular objectives and content states the following[2(1)]:

> I.C.2 "(Curricular) objectives are normally met by a curriculum in which there is a progression in the course work and in which fundamental scientific and other training of the earlier years is applied in later engineering courses."
>
> I.C.3 "The program must not only meet the specified minimum content but must also show evidence of being an integrated experience aimed at preparing the graduate to function as an engineer."

In accordance with these criteria, EM 301 and ME 472 form a progression in course work into the study of energy conversion systems and, therefore, the courses are carefully integrated. This integration is achieved through a course assessment process that will be discussed within the *Course Assessment and Outcomes* section of this paper.

The goal of Thermodynamics is to provide cadets with practical and relevant engineering science background in thermodynamics. The course also provides the groundwork for subsequent studies in engineering sciences and advanced energy topics such as ME 472. EM 301 is designed to provide a solid foundation in classical thermodynamics through the study of three broad topical areas including preliminary topics, methods and tools of analysis, and relevant applications. The topics covered include definitions, pure substances, ideal equation of state, conservation of mass and energy, and the second law as shown on Table 1. In order to enhance the student's learning, several applications are studied in detail including steam power plants, air standard cycles, emissions, vapor compression refrigeration systems, psychrometrics, and air conditioning. The lectures are further augmented by a design project, a tour of a cogeneration plant, and four laboratories focused on steam turbines, SI/CI engine comparison, Cooperative Fuel

Research engines, and gas turbines. Since this course is only one semester long, there are certain topics that are not included due to time limitations. Some of the more notable omissions include exergy, transient systems, thermodynamic property relations, chemical reactions, and phase equilibrium, and thermodynamics of high-speed gas flow.[3, 4]

Over the past several years, ME 472 has evolved into a series of lessons that address three general topical areas: advanced thermodynamics, advanced mechanical system analysis, and direct energy conversion systems. The senior ME major who enrolls in Energy Conversion Systems studies a unique mix of topical areas as motivated by various factors discussed in the *Course Background* section of this paper.

Table 1. Summary of EM 301 Topics

Subject	**Lessons**
Introduction to thermodynamics concepts and	2
Steam tables	2
Ideal gas equation of state and energy transfer concepts	2
1st Law of Thermodynamics	6
2nd Law of Thermodynamics	3
Thermodynamic devices and adiabatic efficiencies	1
Steam vapor power cycles	5
Internal combustion engines	5
Automotive emissions	1
Gas turbine engines	4
Vapor-compression refrigeration cycles	2
Total air conditioning applications (psychrometrics)	2
Review classes	3
Exams	2

In the first portion of the semester, advanced thermodynamic topics including exergy and combustion analysis are studied. These topics are included within ME 472 because they are not studied in the EM301. Furthermore, due to the topics' importance to the mechanical engineering curriculum, exergetic and combustion analyses are introduced first in ME 472 and used throughout the remainder of the semester to evaluate exergetic efficiencies of energy conversion systems and combustion processes. ME 472 cadets can then choose to continue the study of modern thermodynamics during their final semester by selecting a capstone design experience that further emphasizes these topics.

Following advanced thermodynamics, the cadets begin a series of lessons on the analyses of various mechanical systems including refrigeration systems, internal combustion engines, boilers, and fossil fuel-fired steam and gas turbine power plants. The coverage of these topics within ME 472 builds upon an introductory mechanical device portion presented in EM 301. The inclusion of advanced mechanical equipment analysis is motivated by the fact that many of the cadets will require this knowledge at some point in their military careers through acquisition or engineering responsibilities.

The final portion of ME 472 includes a series of lessons on direct energy conversion systems, including fuel cells, photovoltaics, thermoelectricity, thermionics, and magnetohydrodynamics. In addition, supplemental lessons on energy storage, semi-conductors, and nonreactive energy sources (such as solar collectors, wind turbines, and hydroelectric plants) are included. Technological advances as well as the course assessment process discussed later in this paper drove the inclusion of direct energy conversion into this course.

The *Course Background* section of the paper will briefly discuss the evolution of ME 472. The background highlights major topical changes made over the years with respective motivations. The *Course Structure* section focuses on the current course and includes course objectives, syllabus, graded events, projects, field trip summary, and other relevant course information. The last section, *Course Assessment and Outcomes*, includes discussions on the assessment process used for this course and the outcomes based on the current course structure.

II. Course Background

The evolution of the Energy Conversion Systems course at West Point is driven by dynamic factors such as technological developments, current energy policy, military needs, and annual assessment outcomes. In 1994, the course's main goal was to educate students on the analyses of major energy conversion technologies utilized within the United States in the mid 1990's. Topics studied included the analyses of various cycles (such as the spark ignition and compression ignition engines, vapor compression refrigeration, steam power plants) as well as components and processes (such as heat exchangers, coal combustion, gas turbines, boilers, pumps, and compressors).

In 1996, the course began including lessons on advanced thermodynamic analyses, hydroelectric power generation, absorption refrigeration, and air conditioning. All of the additional lessons were added to the course by reducing the scope of topics previously covered in the course. In particular, the lessons on coal combustion were significantly reduced in number. These changes were motivated by an assessment conducted by the primary course instructor at the time. The advanced thermodynamics portion added included five lessons on availability and exergetic efficiency. However, these topics were not revisited throughout the course when various cycles and components were analyzed. Therefore, in 2000, again because of course assessment, exergetic efficiency was integrated throughout the course. For example, the lessons on spark ignition engines now included a series of notes on exergy and exergetic efficiency. The course objectives in 2000 became:

1. Compare and contrast the applications of the First and Second Laws of Thermodynamics with emphasis on solution of problems including uniform-state, uniform-flow systems.
2. Perform combustion analyses.
3. Perform thermodynamic analyses of advanced power generation cycles to include gas and steam power systems and their components.
4. Perform analysis of hydroelectric power generation.
5. Perform thermodynamic analyses of advanced vapor compression refrigeration and absorption refrigeration systems and their components.

In 2001, due to technological developments, current energy policy, military needs, and assessment outcomes, the course again evolved into its current form. A series of fourteen new lessons were added on various forms of direct energy conversion. In order to add these lessons, the following steps were taken:

- The review lessons and notes throughout the course were significantly reduced, thereby requiring the students to review material covered in EM 301 outside of class, if necessary.
- The study of air conditioning was eliminated from the course. Students learn basic design and analyses of typical air conditioning systems in EM 301.
- The time spent studying detailed information regarding selection and design of various power cycle components (such as compressors, cooling towers, and turbines) was reduced. The rationale behind this modification is the premise that this information can be acquired by an engineer "in the field" through readily available handbooks and selection guides.

III. Course Structure

During the fall semester of each year, ME 472 is offered to senior mechanical engineering majors as an advanced elective. The course has a three-credit course value and includes 40 lessons, each 55 minutes in length. The current scope of ME 472 includes the advanced analysis of energy conversion technology, refrigeration, and fossil fuel combustion processes using concepts of exergy. In addition, emphasis is placed on major methods of direct energy conversion including thermoelectricity, photovoltaics, thermionics, magnetohydrodynamics, and fuel cells. In order to encompass this scope, modified course objectives were created as listed below.

1. Compare and contrast the applications of the First and Second Laws of Thermodynamics with emphasis on solution of problems including uniform-state, uniform-flow systems.
2. Analyze advanced power generation systems and components to include gas and steam power cycles.
3. Model exergetic efficiencies for various cycles and determine the exergy at various states throughout the cycle.
4. Analyze combustion processes.
5. Justify usefulness and applicability of various refrigeration systems.
6. Explain fundamental operating principles of direct energy conversion technology including the fuel cell, thermoelectricity, photovoltaics, thermionics, and magnetohydrodynamics.
7. Assess the use of direct energy conversion technologies for military applications.

ME 472 is designed to provide a solid foundation in advanced thermodynamics through the study of three topical areas including exergetic efficiencies, power generation systems, and direct energy conversion technologies as shown on Table 2. In order to enhance the student's learning, several technologies are studied in detail including fuel cells, cogeneration plants, thermoelectric devices for power generation and refrigeration, and photovoltaic devices. The complete listing on all 40 lessons presented in ME 472 is listed as Table 3.

Table 2. Summary of ME 472 Topics

Subject	**Lessons**
Advanced Thermodynamic Analysis	7
Gas and Steam Power Cycles	5
Combustion	3
Power Cycle Components	1
VCRC	1
Absorption Refrigeration	2
Field Trip	1
Direct Energy Conversion Technologies	11
Energy Storage	2
Semiconductors	1
Nonreactive Energy Sources	1
REVIEWS	3
Examinations	2
Total	**40**

Over the course of the semester, two guest speakers from different Army Research Laboratories visited the class to offer their viewpoints and present their current research activities. Each presented a full lesson in their respective area of research, including battery and full cell technologies. The guest speakers each demonstrated actual devices being explored by the military to solve the power source requirements of the soldier in the field. Although the power draw is relatively small (15 to 20 W), it is similar to loads demanded by the electronics industry. Therefore, the students could readily relate this scale of power source with the technology currently used in lap top computers and cellular phones.

The course also includes a full day site visit and tour of a cogeneration plant located in central Pennsylvania. There are cogeneration plants located much closer to West Point then this particular 80 MW facility; however, this plant offers some interesting features that make the three-hour drive worthwhile. First, the plant utilizes culm from abandoned anthracite coalmines as its feedstock. Culm is generally stored in high black banks throughout that region of Pennsylvania. This particular plant sits on a site that includes approximately 150 million tons of culm. Observing several hundred acres of devastated, black land from the rooftop of the cogeneration plant offers an excellent opportunity to help students gain insight into the true cost of energy generation. Although the facility consumes 1800 tons per day of culm in a relatively clean manner, the feedstock supply sitting on this site will last for over 200 years.

In addition to the guest speaker visits and cogeneration plant tour, the students also have the opportunity to enhance their understanding of course material by completing two projects. Project #1 is a 100 point, team-based assignment that involves creating a 15 minute long presentation for students enrolled in Thermodynamics. The content of the presentation must strongly relate to Thermodynamics and have direct relevance to the audience. Detailed information on the project's purpose, objectives, scope, and milestone schedule is included as Figure 1. The phases listed in the milestone schedule section of Figure 1 refer to a design methodology that the ME students learn during their junior year.[5] Performance criteria used to assess and evaluate the student's performance during their oral presentations are included as Figure 2.

Table 3. Detailed Lesson List

ECS-1	COM and First Law of Thermodynamics - REVIEW
ECS-2	Second Law of Thermodynamics – REVIEW
ECS-3	Exergy
ECS-4	Second Law of Thermodynamics Analysis I
ECS-5	Second Law of Thermodynamics Analysis II
ECS-6	Gas Power Cycle - REVIEW
ECS-7	Brayton Cycle - REVIEW
ECS-8	Review
ECS-9	Steam Power Cycle - REVIEW
ECS-10	Cogeneration and Combined Gas-Vapor Power Cycles
ECS-11	**REVIEW**
ECS-12	**WPR-1**
ECS-13	Stoichiometric Combustion
ECS-14	Enthalpies of Formation and Combustion
ECS-15	Adiabatic Flame Temperature and Second Law Analysis I
ECS-16	Second Law Analysis II
ECS-17	*Fuel Cells I*
ECS-18	*Chemical Exergy*
ECS-19	Boilers
ECS-20	Innovative VCRC Systems
ECS-21	Absorption Refrigeration I
ECS-22	Absorption Refrigeration II
ECS-23	**REVIEW**
ECS-24	**WPR-2**
ECS-25	***Trip Section – Cogeneration and Coal Gasification Facility***
ECS-26	*Direct Energy Conversion Technologies/* ***LW Soldier System Demo***
ECS-27	*Energy Storage I /* ***ARL Battery Researcher Visit***
ECS-28	*Energy Storage II*
ECS-29	*Semiconductors*
ECS-30	*Photovoltaic I*
ECS-31	*Photovoltaic II*
ECS-32	*Photovoltaic III*
ECS-33	*Thermoelectricity I*
ECS-34	*Thermoelectricity II*
ECS-35	*Thermoelectricity III*
ECS-36	*Fuel Cells II / ARL Research Scientist Visit*
ECS-37	*Thermionics*
ECS-38	*Magnetohydrodynamics*
ECS-39	*Nonreactive Energy Sources*
ECS-40	**Course Review and Critique – TEE Discussion**

Purpose: Project #1 is a 100 point, team-based assignment that involves creating a 15 minute long presentation for students enrolled in EM301/A, Thermodynamic. The content of the presentation must strongly relate to Thermodynamics and have direct relevance to the audience.

Objectives:

- Improve ability to work effectively on teams.
- Enhance creativity through the creation of a relevant and appropriate presentation.
- Practice ME401 design process.
- Design presentation with your audience in mind.
- Create activities to stimulate audience interest and involvement.
- Assess presentation (following classroom interaction) while focusing on strengths, areas of improvements, and insights gained.
- Apply and strengthen Thermodynamic knowledge through teaching others.

Scope and Details:

- Design a 15 minute long presentation for EM301/A students.
- Create a relevant, interesting talk.
- Include either computer simulations or adequate graphics.
- Establish relevance with audience.
- Discuss a topic that relates to the course material presented in EM301 prior to the date of the presentation. Refer to the attachment for an updated version of the EM301/A Course Syllabus.
- Create activities that engage your audience. (If a cadet falls asleep during your presentation it is an automatic point deduction!)
- All team members must be involved in every IPR and the presentation.
- Assess presentation, focusing on strengths, areas of improvements, and insights gained.

Project Milestone: Deliverables are graded events that are required NLT the dates specified.

24 September	**Deliverables: Proposal Memorandum (10 Points)** Memo must demonstrate completion of the following: Phase I (Identify the Need), Phase II (Plan the Process) Phase III (Develop the Engineering Specs), Phase IV (Develop Concept) 50% complete.
4 October	**Deliverables: In Progress Review #1 (15 Points)** Phase IV (Develop Concept) 100% complete, Phase V (Develop Presentation) 50% complete.
15 October	**Deliverables: In Progress Review #2 (15 Points)** Phase V (Develop Presentation) 95% complete.
5-9 November	**Deliverables: Thermodynamics Presentation (50 Points)**
2 days later	**Deliverables: Self Assessment Memo (10 Points)**

Figure 1. ME 472 Project #1 Information

Performance Criteria	**Score**	**Strengths**	**Areas for Improvement**	**Insights**
Presentation Quality (25 points)				
Total Team Involvement (5)				
Quality of Oral Presentation (5)				
Quality Slide Creation (5)				
Graphic Quality (5)				
Appropriate Length - 15 minutes total (5)				
Presentation Content (25 points)				
Introduction (5)				
Include adequate graphics. (5)				
Establish relevance with audience. (5)				
Engage your audience. (10)				

Figure 2. Performance Criteria for Assessment and Evaluation of Team Presentations

Project #2 is a 150-point, individual assignment that involves critically reading a technical publication, reviewing the publication, and presenting the results to the class in an informal setting. The technical publications selected by the students included books from a wide variety of topics, ranging from artificial intelligence to hybrid vehicle design and infrastructure issues. Detailed information on the project's purpose, objectives, scope, and milestone schedule is included as Figure 3. By their final year in college, most students have written several book reports; however, few engineering majors have written critical book reviews. Therefore, the scope and details section of Figure 3 is supplemented with an attached handout on how to successfully prepare a book review.[6, 7] This summary explains that a book review describes not only what a book is about, but also how successful the book is at what it is trying to accomplish. Reviewers answer not only the WHAT but the SO WHAT question about a book. Thus, in writing a review, the student combines the skills of describing what is on the page, analyzing how the book tried to achieve its purpose, and expressing personal reactions. Performance criteria used to assess and evaluate the student's performance for all requirements associated with Project #2 are included as Figure 4.

The student's ME 472 grade is assigned using the grading scheme included in Table 4. The course has an overall point value of 1500 points. The two in-class examinations are 55-minutes in length and each contribute nearly 17% to the student's overall grade. The examinations are open book and open note. The final examination is three and a half hours in length and cumulative. On the final, the students again reference their textbook(s) and notes from the semester. The homework grade is generally based on homework and short in-class quiz performance. The textbook used in the course is the same as that used in EM 301, Thermodynamics. For advanced topics not covered sufficiently in this text, supplemental reading assignments are provided to the student.

Table 4. ME 472 Graded Event Summary

REQUIREMENT	POINT VALUE	PERCENTAGE
Homework	350	23.3%
Examination 1	250	16.7%
Examination 2	250	16.7%
Projects	250	16.7%
Final Exam	400	26.7%
TOTAL	**1500**	**100.0%**

Purpose: Project #2 is an individual assignment that involves critically reading a technical publication, reviewing the publication, and presenting your results to your class in an informal setting.

Objectives:
- Promote scholarly curiosity and research.
- Practice careful analytical reading.
- Enhance life long learning abilities.
- Enhance creativity through the creation of a relevant and appropriate review and discussion.
- Strengthen assessment and evaluation abilities through preparation of book review.

Scope and Details: *(Refer to enclosure for more information.)*
- Critically read a technical publication (approved by course instructor).
- Prepare a book review (approx. 1200 words).
- Present your book review in an informal setting to your peers.

Grade Plan and Project Milestone: Deliverables are graded events that are required NLT the dates specified.

PROJECT #2	Suspense	POINTS
Book Review Rough Draft	Wednesday, 28 NOV 2001	25
Book Review Submission	Wednesday, 5 DEC 2001	100
Presentation	TBD	25
TOTAL		**150**

Figure 3. ME 472 Project #2 Details

ROUGH DRAFT *Score: /25*

Performance Criteria	**Score**	**Strengths**	**Areas for Improvement**	**Insights**
Appropriate Length – 1200 words				
Spelling/grammatical errors (2 point deduct each)				
Late penalty				
Std. Book Review Format (5 points)				
Heading (2 points)				
Introduction (3 points)				
Background Information (3 points)				
Summary (4 points)				
Evaluation (5 points)				
Conclusion (3 points)				

BOOK REVIEW *Score: /100*

Performance Criteria	Score	Strengths	Areas for Improvement	Insights
Appropriate Length – 1200 words (5 points)				
Spelling/grammatical errors (2 point deduct each)				
Late penalty				
Std. Book Review Format				
Heading (5 points)				
Introduction (15 points)				
Background Information (15 points)				
Summary (15 points)				
Evaluation (30 points)				
Conclusion (15 points)				

PRESENTATION *Score: /25*

Performance Criteria	Score	Strengths	Areas for Improvement	Insights
Introduction (5 points)				
Background Information (5 points)				
Summary (5 points)				
Evaluation (5 points)				
Conclusion (5 points)				
Engage your audience. (5 BONUS)				

Figure 4. Performance Criteria for Book Review, ME 472 Project #2

IV. Course Assessment and Outcomes

Ideally, assessment methods are applied consistently semester to semester and should be part of an integrated program of assessment and feedback to affect positive change or maintain superior performance.[8] Over the course of the last five years, the faculty within the Department of Civil and Mechanical Engineering have developed and refined an assessment tool called a *course assessment plan*. This plan is written once a year for all courses taught within the department. The plan includes a written draft and an oral presentation. The course's professor prepares the draft for a small course like ME 472. It includes a collection of narratives, assessment data, analysis of data, and proposed course revisions. Included in Figure 5 is a sample outline for a typical course assessment plan.

The professor develops the written course assessment plan for ME 472 each spring in preparation for an oral presentation to the department head and other interested individuals at various levels of curriculum management. In addition to those who manage the curriculum, all interested stakeholders are invited to attend the briefing to ensure that their interests are met. Typical attendees for the ME 472 presentation include those who teach Thermodynamics, Heat Transfer, and Fluid Mechanics. During the presentation, the ME 472 professor highlights the content from the written document. The ensuing open discussions during the presentation assist the professor with any necessary final revisions to the document. The final document is forwarded to the department head for signature and then maintained for a period of at least five years by the ME 472 professor.

The course assessment plan serves many purposes and provides ample outcomes. From the ME 472 professor's perspective, it is an opportunity to collect all of the previous year's assessment data into one package with narrative that attempts to quantify what the data represents. If potential changes are identified for the course in the following academic year, the professor's suggestions along with supporting narrative describing resource and/or curriculum impact are included. As discussed in the *Course Background* section of this paper, suggested course changes are often due to a change in current technology, text or teaching techniques, or feedback via course assessment. From a departmental perspective, the course assessment plan provides an opportunity to review annually each course to ensure that it is integrated within the department supporting the current vision and maintaining its links fore and aft to sequential courses. The department has found the course assessment plan a great means for reducing redundant material and allowing courses to truly build upon each other. In addition, the plan provides a running history of all courses within the department and assists in creating a foundation of narratives and statistics upon which to base both internal and external program reviews.[9]

Sample Course Assessment Plan Outline

1. **Course Description**
   - University academic course description
   - Course enrollment for current year and projection for following academic year
   - Course objectives
   - Textbooks used in the course
   - Course syllabus outlining topics and assignments
   - Course standard policies

2. **Course Assessment**
   - Narrative assessment by course director referencing qualitative statistics.
   - Narrative assessment of how the course supported the current course, departmental and Academy goals.
   - Narrative assessment of how the students accomplished the course goals.
   - Summary of the student feedback from web-based surveys. This summary allows the course director to compare the course to other departmental courses and all USMA courses.
   - Course average grades for the last five semesters using a criterion-referenced grading system.
   - Course average time data. Students are requested to complete a time survey each lesson that records the amount of time the student spent working on the course since the last lesson period. This data is tracked for the five previous semesters. Refer to [10] for more details on how this information can be used as an assessment tool.

3. **Course Recommendations**. Any proposals for change are included in this section. All proposals for change are justified based upon the previous assessment. Justification and impact statements are included for all proposed changes.

Figure 5. Sample Outline of Course Assessment Plan Document

Although the full course proposal plan has not yet been created for next fall's offering of ME 472, the data collection, data analysis, and narrative preparation processes are in progress. The data is available from time surveys and the web-based course-end survey completed by the students enrolled in ME 472. As discussed in Figure 5, students are requested to complete a time survey each lesson that records the amount of time the student has spent working on the course since the last lesson period. This data is tracked for the previous semesters of ME 472 and its review is useful in judging course work load and patterns throughout the semester.[10] Table 5 includes this information for ME 472 from 1996 through 2001. Note that although there were several new topics added to ME

472 this past semester, the average time spent by the student outside of class increased by only 10%.

Table 5. Time Survey Results and History

Semester	**Average Time/Lesson (min)**
Fall 2001 (021)	78
Fall 2000 (011)	70
Fall 1999 (001)	41
Fall 1998 (991)	53
Fall 1997(981)	54
Fall 1996 (971)	41

In addition, a sample of the relevant feedback responses from the fall 2001 semester is included in Table 6. The values listed in parentheses correspond to results obtained in fall 2000. From preliminary analysis of the numerical data, it appears that the course is slightly improving in several areas. These improvements could be attributed to the changed course scope; however, determining the precise reason for the change is difficult given the data available. Course-end data is typically most useful in highlighting potential areas of improvement. For example, when the student was asked in Question E.5 whether they agreed with the statement:

> *"I can explain fundamental operating principles of direct energy conversion systems including fuel cells, thermoelectricity, photovoltaics, thermionics, and magnetohydrodynamics."*

They responded with a mean value of 3.75, which is below the value of 4 corresponding to "agree" as listed in Table 6. In addition, on the written feedback obtained during the course-end survey, several students noted the difficulty of not having a course text for the topics covered in the later part of the semester (referenced in Question E.5). These results clearly indicate that there is still much room for improvement in the later part of the course. The final recommendations for the course next fall will be discussed during the ME 472 course proposal presentation in late spring of 2002.

V. Summary

Energy Conversion Systems (ME 472), offered by the Mechanical Engineering Program at West Point has evolved into a cohesive series of lessons addressing three general topical areas: advanced thermodynamics, advanced mechanical system analysis, and direct energy conversion systems. In the first segment of the course, students study advanced thermodynamics topics including exergy and combustion analysis. The students then analyze various mechanical systems including refrigeration systems, internal combustion engines, boilers, and fossil fuel-fired steam and gas turbine power plants. Throughout the semester, exergetic efficiencies are determined on various equipment and systems. The final portion of the course is new as of 2001 and includes several lessons on direct energy conversion technologies, such as fuel cells, photovoltaics, thermoelectricity, thermionics, and magnetohydrodynamics. Supplemental lessons on energy storage, semi-conductors, and nonreactive energy sources (such as solar collectors, wind turbines, and hydroelectric plants) are included here for clarity.

This paper discusses the evolution of ME 472 over the past several years and explains the motivations for the course's progress. In addition, the current course objectives, syllabus, graded events, project descriptions, field trip summary, and other relevant course information are discussed in detail. The final section of the paper includes a discussion on the assessment process used for ME 472 and a few example outcomes of the assessment process are presented. The evolution of a course like Energy Conversion Systems is driven by dynamic factors such as technological developments, current energy policy, military needs, and annual assessment outcomes. Therefore, the goal is not to find a final course product and remain static for several years, but instead to continue evolving the course into directions that make sense.

Table 6. Course-end Feedback Data (2001)

Note: Values shown in parenthesis refer to last semester's values, CME refers to the Civil and Mechanical Engineering Department, ME Div is the ME Program within CME.

Survey Question	USMA	CME	ME Div	ME472
A.2 This instructor used effective techniques for learning, both in class and for out-of-class assignments.	4.24	4.39	4.34	4.50 (4.00)
A.6 My motivation to learn and to continue learning has increased because of this course.	3.93	4.08	4.11	4.38 (4.33)
B.1 This instructor stimulated my thinking.	4.24	4.32	4.29	4.63 (4.33)
B.2. In this course, my critical thinking ability increased.	4.05	4.27	4.26	4.50 (4.33)
D.6 This course improved my ability to communicate effectively with clear, critical thinking skills required of a junior Army officer and within the context of solving mechanical engineering problems.			4.1	4.50 (4.00)
D7. This course improved my knowledge of contemporary issues and an understanding of the impact of engineering solution on the Army, the nation, and in global contexts.			4.02	4.63 (4.00)
D.8 I feel my ability to continuously improve and engage in life-long learning to adapt to a technologically advancing Army has improved because of this course.			4.09	4.13 (4.17)
D9. My ability to use the techniques, skills, and modern engineering tools necessary for engineering practice has improved because of this course.			4.18	4.38 (4.00)

*Scale: 1 = unsatisfactory; 2 = marginal; 3 = satisfactory; 4 = above average; 5 = excellent.

Survey Question	USMA	CME	ME Div	ME472
E1. I can compare and contrast the applications of the 1st and 2nd Laws of Thermodynamics with emphasis on the solution of problems including uniform-state, uniform-flow systems.				4.25
E2. I can analyze advanced power generation systems and components to include gas and steam power cycles.				4.38
E3. I can analyze combustion processes.				4.63
E4. I can justify the usefulness and applicability of various refrigeration systems.				4.25
E5. I can explain fundamental operating principles of direct energy conversion systems including fuel cells, thermoelectricity, photovoltaics, thermionics, and magnetohydrodynamics.				3.75
E6. I can adequately assess the use of direct energy conversion technologies for military applications.				4.13

*Scale: [5] Strongly agree, [4] Agree, [3] Neutral, [2] Disagree, [1] Strongly disagree

VI. Bibliography

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