A Modern Mechanical Engineering Sequence for the United States Military Academy

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Abstract

Many institutions are revising their engineering curricula and developing programs and courses to meet the needs of industry. With or without the valuable, external assessments of engineering programs from ABET's EC2000 Criteria, engineering educators cannot ignore the changes in real world engineering and design. Engineering programs must prepare their graduates for success beyond the classroom. The future of engineering points at more interdisciplinary work and more work performed in teams. This paper focuses on a proposed mechanical engineering sequence at the United States Military Academy that incorporates traditional mechanical engineering courses as well as new, interdisciplinary courses. The design of this proposed curriculum proceeds from a consideration of the Academic Program Objectives for the institution as a whole, flows through the objectives for the Mechanical Engineering Program, and results in a new Mechanical Engineering Program to meet those objectives. There are three modules composing the foundation for this mechanical engineering sequence: Thermo-fluids, Mechanical Systems (Mechatronics), and Mechanical Design. The traditional engineering courses such as Thermodynamics give the student a fundamental understanding of basic laws and physical systems. The interdisciplinary courses such as Mechanical Design or Mechatronics expose the student to an environment where there are many correct solutions and allow him or her to function and perform as a valuable member of a design team. The proposed curriculum would provide the robust essential engineering education and substantial preparation in design, analysis, communication, and teamwork in a four year mechanical engineering program. We discuss the design of the assessment system to measure the effectiveness of this curriculum. We believe this curriculum is a model that many mechanical engineering institutions will find useful to prepare their graduates and concurrently meet the needs of their customers.

I. Introduction

The United States Military Academy (USMA) is the sole college in the nation whose only responsibility is to prepare every one of its students for professional service as a regular Army officer. The academic program, like the other aspects of the West Point environment, is designed to foster development in a wide variety of traditional subjects in the humanities and sciences essential to such service. This paper will focus on the development of an integrated mechanical engineering curriculum at USMA and show how it meets the needs of the institution and the engineering profession.

USMA must prepare its mechanical engineering graduates to meet diverse expectations in a technical army and in careers beyond the military. They need experience and exposure with the discipline's wide range of topics. By providing students the opportunity to study a broad and balanced choice of mechanical engineering offerings, the Academy responds to the requirements for graduates with the capabilities to solve complex, ill-defined problems and who are prepared for advanced schooling in a wide range of technical areas.

However, studying a vast set of topics may make the curriculum disjointed and the topics appear unrelated. Students may see mechanical engineering as a pursuit of many subjects with no mastery in any area. The solution may very well be an integrative experience or course that ties many of the subject areas together and shows relevant application to many of the topics. Such an experience can promote interests in mechanical engineering beyond the classroom fundamentals.

Additionally, designing a meaningful integrative mechanical engineering experience is an excellent opportunity to realign the curriculum with the needs of society. The three modules of mechanical engineering presented in this paper offer a study in depth of undergraduate mechanical engineering. By employing three modules, this curriculum avoids a cumulative exposure to a specific matter and, at the same time, introduces related material from other disciplines. Likewise, the proposed curriculum still demands the knowledge acquired in previous courses. This sequential learning leads to a more refined understanding of subject material and promotes greater efforts at synthesis and analysis.

This mechanical engineering curriculum concludes in a substantial project or course after the student has demonstrated a good understanding of the fundamentals of the discipline. In the American Association of Colleges' (AAC) view, this experience provides two great lessons: 1) the joy of mastery, the thrill of moving forward in a formal body of knowledge and gaining some effective control over it, integrating it, perhaps even making some small contribution to it; and 2) the lesson that no matter how deeply and widely students dig, no matter how much they know, they cannot know enough[1].

II. Academic Program Goals and ME Program Outcomes and Objectives

The task of developing a modern mechanical engineering experience for students originates from the Academic Program Goals of USMA. Results of an ongoing assessment process demonstrate that the Academic Program is meeting its goals and the curriculum is evolving to better meet those goals[2]. The mechanical engineering program had been evolving to meet new demands and interests, but these changes were primarily on the course level. A recent USMA committee reviewed the current curriculum and recommended changes to the goals and curriculum. The revised Academic Program Goals of USMA are reflected in the following statement:

We expect graduates to "anticipate and respond effectively to the uncertainties of a changing technological, social, political, and economic world." Graduates must have experience and competence in the following areas:

1) Moral Awareness
2) Communications
3) Culture
4) History
5) Human Behavior
6) Mathematics and Science
7) Information Technology
8) Engineering and Technology
9) Creativity
10) Continued Educational Development

The goal of the Mechanical Engineering program is to support USMA's General Educational goal by providing high quality instruction in a positive learning environment in the discipline of Mechanical Engineering leading to an ABET-accredited degree recognized as being among the best in the nation. The Mechanical Engineering program stresses engineering fundamentals so that graduates are well equipped to understand complex technical problems in a rapidly changing, high-technology Army. On completing the program, the graduate is well-prepared to excel as an officer and an engineer. The practice-oriented degree is strengthened by the complete integration of design and laboratory experience throughout the curriculum[1].

To meet this goal, the objectives of the Mechanical Engineering program are to produce graduates who, within three to six years after graduation, successfully:

1) Learn the philosophical basis for the practice of engineering that applies an engineering thought process and uses design to solve problems of the Army and the nation.
2) Develop an understanding of, and appreciation for, the natural physical laws and technology, particularly as they apply to mechanical engineering.
3) Internalize the design process and develop creativity in problem solving.
4) Demonstrate the necessary leadership and teamwork skills to work in multidisciplinary team environments.
5) Demonstrate those elements of engineering practice that prepare graduates for advanced study in mechanical engineering or other technical areas to include possible admission into and success at top mechanical engineering graduate programs.
6) Communicate, orally and in writing, correctly and in precise terms and correctly with each communication evincing clear, critical thinking.
7) Are committed to continuous improvement and life-long learning with the flexibility to adapt to changing Army needs.

In order to have graduates meet the mechanical engineering program objectives, a set of desired outcomes, measurable upon completion of the program of study, support the program objectives. The mechanical program outcomes mirror ABET's EC2000 [3]. A student who qualifies for graduation with a mechanical engineering major from USMA must be able to demonstrate the following outcomes:

1) An ability to identify and formulate engineering problems and apply their knowledge of mathematics, science, and engineering along with creativity skills to solve those problems in mechanical engineering and Army contexts. [ABET Criterion 3 Outcomes (a) and (e)]
2) A familiarity with statistics and linear algebra, a knowledge of chemistry and depth in calculus-based physics, and an ability to apply advanced mathematics through multivariate calculus and differential equations to solve mechanical engineering problems. [ABET Criterion 8 Program Criteria]
3) An ability to function professionally and with ethical responsibility as an individual and on multidisciplinary teams. [ABET Criterion 3 Outcomes (d) and (f)]
4) An ability to design and realize thermal and mechanical systems, components, or processes to meet the needs of the mechanical engineering discipline, the Army, or the nation. [ABET Criterion 3 Outcome (c) and ABET Criterion 8 Program Criteria]
5) An ability to design and conduct experiments, as well as to analyze and interpret data to support the mechanical engineering design or problem solving process. [ABET Criterion 3 Outcome (b)]
6) An ability to communicate effectively with clear, critical thinking skills required of a junior Army officer and within the context of solving mechanical engineering problems [ABET Criterion 3 Outcome (g)]
7) A knowledge of contemporary issues and an understanding of the impact of engineering solutions on the Army, the nation, and in global contexts. [ABET Criterion 3 Outcomes (h) and (j)]
8) An ability to continuously improve and engage in life-long learning to adapt to a technologically advancing Army [ABET Criterion 3 Outcome (i)]
9) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice [ABET Criterion 3 Outcome (k)]

The mechanical engineering program objectives strongly support USMA's Academic Program Goals mentioned above. In order to meet the mechanical engineering program objectives, students must experience a mechanical engineering curriculum that purposefully facilitates the desired outcomes. A complete sample program including all core courses for a mechanical engineer is in Section VI. The modules of mechanical engineering courses presented in the next sections are the purposeful arrangement of experiences that will assist the deliberate progression in students' capabilities. The three modules of mechanical engineering and their specific courses are summarized in Table 1. These proposed mechanical engineering modules and courses help the mechanical engineering program meet the goals of the institution and the engineering profession.

Table 1: Mechanical Engineering Modules and Courses

Thermal-Fluid Systems	**Mechanical Systems (Mechatronics)**	**Mechanical Design**
Classical Thermodynamics	Statics and Dynamics	Computer Aided Design
Fluids	Mechanics of Materials	Introduction to Design / Machine Elements
Heat Transfer	Vibrations	Mechanical Design
Vehicle Power Plants *or* Intro to Aerodynamics	Control Systems	Engineering Materials
Elective	Vehicle Dynamics *or* Aircraft Performance & Static Stability	Capstone Design
	Elective	

The three modules provide common concepts and lend themselves to sequential learning within the groups. The importance and integration of the courses within the groupings follows in the subsequent sections.

III. Thermal-Fluid Systems

Increased importance on energy conservation and awareness in nearly every sector of society specifically compels all mechanical engineering students to have a fundamental knowledge of energy. Mechanical engineers must understand energy uses, transfer, interactions, limitations, and conversions. A basic understanding of the thermal sciences fosters the awareness and appreciation for the relationship between energy and work. The ability of the mechanical engineer to function on a multi-disciplinary design team with civil, electrical, industrial, and architectural engineers is enhanced by a working knowledge of Thermal-Fluid Systems. The Thermal-Fluid Systems module of the curriculum supports mechanical engineering objectives 2 and 5. Laboratory courses within the group include Thermodynamics, Fluids, Vehicle Power Plants, and Introduction to Aerodynamics.

Major topics in the Thermal-Fluid Systems from several textbooks[4,5] echo the importance of understanding fundamental thermodynamics before studying fluids and heat transfer. A sequential approach is used in this module to build upon thermodynamics and find similarities with previous knowledge. All subcategories in the Thermal-Fluid Systems stress material properties, the transfer of energy into work, and basic conservation laws. Integration of the course materials comes primarily with the Vehicle Power Plants or the Introduction to Aerodynamics courses. An elective, Energy Conversion and Power Systems, also incorporates material from all the courses in this module.

IV. Mechanical Systems (Mechatronics)

The integration of mechanical, electrical, and control systems has broadened the mechanical engineering discipline to incorporate more electrical and feedback comprehension. Encompassing electrical and feedback topics into the study of mechanical systems allows products to be developed through concurrent design rather than designing a product by discipline. The Mechanical Systems module supports mechanical engineering objectives 2 and 5. Laboratory courses in this assembly include Mechanics of Materials, Control Systems, Vehicle Dynamics, and Aircraft Performance.

A review of several textbooks[6,7,8,9,10] in this module discloses the relationships in what seems to be very diverse topics. An integrative approach is used to bring the subjects together. Vibrations is mathematically modeling basic physical systems. Electrical engineering gives the students a fundamental knowledge in another discipline and an introduction to control and model more physical and mechanical systems. A controls course demonstrates specific application and integration between the mechanical, electrical, and control components of a system. The Vehicle Dynamics or Aircraft Performance course demonstrates these smaller, simple systems as part of a larger, more complex system and brings together the different components of these individual courses.

V. Mechanical Design

Design is the core of mechanical engineering activity, integrating math and engineering science knowledge to develop or improve a specific product. It is an interdisciplinary activity that is best learned by doing, often resulting in various solutions. Design includes techniques, methodology, decision-making, optimization, engineering economy, and planning. The Mechanical Design module supports mechanical engineering objectives 1, 3, 4, 6, and 7. Laboratory courses in this module include Computer Aided Design and Engineering Materials.

A combination sequential and integrative approach joins together this module. Computer aided design gives the students the ability to communicate their product in a professional manner. Mechanical design starts with introducing the design process and exercising it. Several textbooks on design stress the importance of having a method or framework in which to begin the design process and seek a viable solution in an unknown environment[11,12,13]. The mechanical design module incorporates some science but stresses the process and teamwork, making it a continuous experience. The capstone course builds on and reinforces the design process and ideally integrates material from all three modules, drawing on previously acquired knowledge and concepts as well as prompting the students' interest to look beyond the normal coursework.

VI. Integration

The total engineering process is a team effort. To be effective, there must be excellent communications between the products users' and all the engineers involved in the various phases of the design process. The best way to integrate knowledge from a variety of courses and individual efforts into a meaningful process is through a major design experience, often a capstone design, which requires students to exercise skills from the entire mechanical engineering curriculum. This major design experience should also require students to seek and learn more material in depth as part of the process.

When integrating the mechanical engineering modules, there are three ways that quickly come to mind to bring the courses together: 1) an Introduction to Engineering course, 2) a Capstone project, and 3) an Integrated Experience course. Many institutions already use an Introduction to Engineering course, and showing the "big picture" early is a good method to generate interest in mechanical engineering. The Capstone project has the benefits already cited but may not include some of the disciplines and allows students to work in their areas of interest. The Integrative Experience course may offer some benefits to all students.

This last option for an integrative experience is a course that guides students along a major design effort and allows them to see many applications from the different courses. Such a course could be introduced at the beginning of the mechanical engineering curriculum to generate interest in the material or as a point of reference when studying concepts in more detail later. Perhaps a more beneficial placement of this integrative experience course is near the end of the mechanical engineering curriculum to bring many of the subject areas together and to help reinforce developmental concepts from concurrent courses. The advantages to an integrated approach have been cited in previous literature[14,15]. When students learn the relevance of basic course material, that material becomes more significant which increases the students' motivation to learn.

An example integrative experience course might be the design of an airplane or ground vehicle. Topics would focus on different components of the larger system and show the relevance of the different subjects in the mechanical engineering curriculum. The Thermal-Fluid Systems topics could be the engine – energy and ideal cycles, cooling systems, heat shielding, and aerodynamic drag on the vehicle. Areas for Mechanical Systems might be the vehicle suspension, recoil of a weapon subsystem, wing vibrations, and control of some of the subsystems with electrical components. Mechanical Design could incorporate design of some components such as gears or springs. Again, this Integrative Experience course shows the subsystem relationships on a larger, familiar system and the relevance of the diverse topics in mechanical engineering. It would reinforce the design process and group work. The Integrative Design course has the structure to integrate the different modules and courses in a mechanical engineering program while retaining the flexibility for student creativity and ensuring different solutions for like problems.

The entire curriculum for a USMA mechanical engineer is in Table 2. The shaded boxes indicate core course required of all graduates of USMA. The large core requirement of all students requires placement of certain courses in specific years. Ideally, the mechanical engineer would have more exposure to engineering courses earlier in the curriculum. This model indicates the integrative experience / course near the end of the curriculum in the bold bordered box.

Table 2: USMA Mechanical Engineering Curriculum

Freshmen	Math	Chemistry	Psychology	History	English	
	Calculus I	Chemistry	Information Technology	History	Literature	
Sophomore	Calculus II	Physics	Philosophy	Political Science	Foreign Language	
	Eng. Math	Physics	Statics & Dynamics	Economics	Foreign Language	Physical Geography
Junior	Thermo	CAD	Electrical Engineering	Strengths of Materials	International Relations	Leadership
	Fluids	Intro to Design	Vibrations	Probability & Statistics	Auto / Aero	Advanced Comp
Senior	Heat Transfer	Mechanical Design	Controls	Auto/Aero		Military Art
	Materials	Capstone *or* Integrative Experience	Elective	Seminar	Law	Military Art

VII. Expected Outcomes and Assessment Design

Given the limited time available to explore each module, this mechanical engineering curriculum is designed to promote a way of thinking and encourage education and interests in mechanical engineering. Additionally, this curriculum allows students to function effectively as a mechanical engineer on a multidisciplinary design team. In assessing the curriculum, we must determine: 1) the appropriate level of success at the undergraduate level, and 2) appropriate techniques to assess the minimum acceptable level of achievement.

There are several ways to measure or assess the knowledge gained from the different courses in the curriculum. Standardized tests such as the Fundamentals of Engineering Exam (FEE), performance of design teams on capstone projects, assessments from capstone customers and faculty advisors, and standardized course feedback surveys are current methods used to assess courses and the engineering curriculum. These are great gauges for the individual courses, but assessing the overall program is more subjective.

However, implementing a way to assess the integration of the courses may be more difficult than revising the curriculum. The integration of the mechanical engineering curriculum takes place over five semesters, culminating in an integrative experience. Students may lack the ability to see the “big picture” of the purpose in the curriculum when they are focused on the tangibles of a current semester. They should be able to see a continuum of their engineering knowledge and be able to recognize the relationships of engineering problems. There appears no easy, completely objective way to assess the degree of integration of engineering knowledge. In the meantime, we can continue to use subjective assessments such as instructor observations and student comments on course surveys coupled with objective questions concerning the integrative experience course. Placement of the integrative experience course at the end of the curriculum only means any feedback will not be available for years, and any shortcomings cannot be corrected before students graduate. The assessment tools must provide information back to the students so they know the areas for personal improvement as well as program feedback to improve the curriculum and manage resources. A truly accurate method to assess the integration of the curriculum is not available at this time.

VIII. Conclusion

The diversity of subjects in mechanical engineering may cause a curriculum to appear segmented with students experiencing a wide variety of topics in Thermal-Fluid Systems, Mechanical Systems, and Mechanical Design. However, by integrating and building on the subjects in three modules, and integrating the three modules themselves, students can see better the relationships between the different subjects in mechanical engineering. Such a restructuring of the curriculum must support the goals and objectives of the mechanical engineering program, the institution, and the needs of society. The revision of the USMA mechanical engineering program meets the higher needs of the engineering profession and the institution and brings seemingly diverse topics together through an integrative experience course. However, the assessment of this integrative experience course is an ongoing study and data will not be available in the near term.

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