

A PROPOSAL FOR AN INTEGRATED MECHANICAL ENGINEERING PROGRAM AT THE UNITED STATES MILITARY ACADEMY

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Abstract

This paper presents a proposal for an integrated, project-based mechanical engineering curriculum. Several justifications support this significant change to the existing curriculum. This paper discusses the advantages of an integrated curriculum that enables tomorrow's engineers to meet the multidisciplinary challenges of the future. This integrated curriculum satisfies the Accreditation Board for Engineering and Technology (ABET) engineering criteria, and thus supporting program outcomes and objectives. Adoption of the integrated curriculum provides flexibility to add new and innovative courses. Course recommendations within this proposal include the addition of an Introduction to Engineering course—a multidisciplinary first-course for engineering majors of all disciplines—and other specialized electives, including the possibility of distance learning. An integrated curriculum also lends itself to a project-based learning model that is especially beneficial to engineering education. Finally, the proposed changes focus on bridging the gap between a structured, compartmentalized high school curriculum and an unstructured, open-ended graduate school experience. This paper presents current and proposed curricula, to include course “tracks”—the result of combining several current courses—and recommendations for new courses and specialized electives.

INTRODUCTION

The Department of Civil and Mechanical Engineering at the United States Military Academy (USMA) is currently investigating a new way of integrating courses within its curriculum. There are several reasons why the department wants to examine this issue. First, the structured environment of the USMA limits the number of electives available while emerging technologies continue to expand the number of engineering topics. Second, students tend to view each course as being very distinct, instead of understanding that there are a few guiding laws and principles that govern all of engineering. Integrating courses, as described within this paper, offers solutions to these problems. In addition, there appear to be many other advantages to restructuring the curriculum in this fashion. This paper addresses the changes proposed within the Mechanical Engineering Division of the Department of Civil and Mechanical Engineering.

The United States Military Academy (USMA).

The United States Military Academy (USMA) at West Point, New York, is located about 50 miles north of New York City. It was founded in 1802 as an academy that educates officers for the United States Army. In 1812, the USMA recognized the importance of engineers both in the Army and in civil projects to build a young nation. The curriculum was therefore changed to meet this need. Today the USMA is still known primarily for its engineering programs, although it also offers a wide variety of other majors. The USMA is one way that officers may be commissioned in the United States Army. Its mission 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

There are approximately 4,000 students called cadets at the USMA. The USMA annually screens approximately 10,000 applicants for grades, athletics, extra-curricular activities, and physical fitness. Applicants must also receive a nomination from one of their state’s congressmen. This lengthy process results in about 1,300 cadets being admitted to the USMA each year, however, the graduating class size is typically less than 1000 by the end of the four years. These strict standards ensure high quality personnel enter the Army officer corps.²

Today the USMA offers a wide variety of majors from which cadets may choose. Twenty-five majors and 16 fields of study are offered in the mathematics, science, and engineering disciplines. Seven of these majors are accredited by the Accreditation Board for Engineering and Technology (ABET). Forty-three majors and 52 fields of study are offered in the humanities and public affairs disciplines. All cadets take a core curriculum that makes up the majority of their first two years. Figure 1 shows this core curriculum.³

SUBJECT	NUMBER OF COURSES	CREDIT HOURS
Freshman Year		
Chemistry	2	6
Information Technology	1	3
English	2	6
History	2	6
Leadership	1	3
Mathematics	2	8.5
Sophomore Year		
Economics	1	3.5
Foreign Language	2	7
Mathematics	2	7.5
Philosophy	1	3
Physical Geography	1	3
Physics	2	7
Political Science	1	3.5
Junior Year		
English	1	3
Leadership	1	3
International Relations	1	3.5
Military History	2	6
Senior Year		
Law	1	3.5

Figure 1: USMA Core Curriculum

In addition to the core curriculum, non-ABET engineering majors must take a three-course engineering sequence and an additional information technology course. During their second year at the USMA, cadets choose their major or field of study and, if required, their three course engineering sequence. The seven engineering sequences offered are Civil Engineering, Computer Science, Electrical Engineering, Environmental Engineering, Mechanical Engineering, Nuclear Engineering, and Systems Engineering. All cadets' selected program of study includes an integrative experience. The 26 core courses and four additional courses make the core academic experience at USMA very unique.

Department of Civil and Mechanical Engineering.

The Department of Civil and Mechanical Engineering is one of thirteen departments at the USMA. Its mission is to “educate and inspire cadets in civil engineering, mechanical engineering, and engineering mechanics such that each of these cadets is a commissioned leader of character who is committed to duty, honor, country; a career in the United States Army; and a lifetime of service to the nation.”⁴ The Department accomplishes this mission by offering an extensive engineering curriculum that supports and complements the comprehensive core curriculum. The Mechanical Engineering Division offers an ABET-accredited Bachelor of Science degree in mechanical engineering with a concentration in either General Mechanical Systems or Aeronautical Systems. Figure 2 summarizes the courses with their associated semesters for these two mechanical engineering concentrations.⁵

AERONAUTICAL SYSTEMS			GENERAL MECHANICAL SYSTEMS	
Course	Semester		Semester	Course
Statics and Dynamics	Second	SOPHOMORE	Second	Statics and Dynamics
Engineering Mathematics	Second		Second	Engineering Mathematics
Probability and Statistics	First	JUNIOR	First	Electrical Engineering
Thermodynamics	First		First	Thermodynamics
Fluid Mechanics	First		First	Fluid Mechanics
Mechanics of Materials	First		First	Mechanics of Materials
Engineering Materials	First		First	Vibration Engineering
Computer Aided Design	Second		Second	Computer Aided Design
Electrical Engineering	Second		Second	Probability and Statistics
Introduction to Design	Second		Second	Introduction to Design
Introduction to Aerodynamics	Second		Second	Mechanical Power Plants
Mechanical Design	First		SENIOR	First
Dynamic Modeling and Control	First	First		Dynamic Modeling and Control
Aerodynamic Performance and Stability	First	First		Heat Transfer
Vibration Engineering	First	First		Mechanical Power Trains
Heat Transfer	Second	Second		Engineering Materials
Seminar	Second	Second		Seminar
Helicopter Aerodynamics, Engineering Computing, or Structural Analysis	Second	Second		Structural Mechanics or Energy Conversion Systems
Aerodynamic Systems Design	Second	Second		Mechanical System Design

Figure 2: Aeronautical Systems and General Mechanical Systems Concentrations

A unique blend of faculty members executes this academic program. Three permanent military faculty, fifteen rotating military faculty, and four civilian faculty compose the Mechanical Engineering Division. The academic ranks of the faculty include instructor, assistant professor, associate professor, and professor. The rotating military faculty members include primarily Army officers with one Navy officer and one Air Force officer. These officers have an average of thirteen years of military service. Rotating faculty members teach at USMA for three years and then transfer to other military assignments. Three of the rotating faculty members are at USMA for the second time in their careers.

THE MOTIVATION TO INTEGRATE COURSES

The current mechanical engineering program provides a strong foundation in fundamentals. Each year all mechanical engineering majors must take the Fundamentals of Engineering (FE) exam. The 94% pass rate for the April 2002 FE exam is a strong indicator of the strength of the mechanical engineering program at USMA. The mechanical engineering program ranks 5th among schools without an engineering doctorate program in the 2003 edition of *U.S. News and World Report* rankings.⁶ Despite this success, improvements to the program may be realized by integrating parts of the curriculum.

The details of how courses could be integrated will be explained later in this paper.

Before discussing, however, it is important to understand why curriculum integration is beneficial. Curriculum integration involves combining topics in existing courses currently taught as separate subjects into a sequence of courses based on the same governing laws and principles. With a strong foundation in the basics, students explore aspects of the related topics needed to solve complex problems. One example is combining thermodynamics, fluid mechanics, and heat transfer—currently offered as separate one-semester courses—into a two-semester thermal sciences sequence that draws on the conservation of mass, energy, and momentum laws to teach students. Massachusetts Institute of Technology currently uses this approach in its Thermal-Fluids Engineering I and II courses.⁷ There are five benefits to creating this type of program—students gain a better understanding of basic principles, the program better satisfies outcomes and objectives, opportunities for project-based learning increase and potentially allowing students to function on multi-disciplinary teams, the gap between undergraduate and graduate studies is bridged, and more elective opportunities exist. Each of these advantages is discussed in detail.

Better Understanding of Basic Principles.

One of the inefficiencies of the semester-based engineering curriculum at the USMA is redundancy—the loss of lesson periods due to review of fundamental concepts introduced in a previous course. An advantage of integrating the curriculum is that students gain a better understanding of basic principles without redundant lesson periods. In this integrated approach, basic principles that apply to all subjects within a track are introduced initially. The relevance of these basic principles is then reinforced as individual topics within the track are covered.

Another disadvantage of the existing program is the myriad of textbooks adopted, most of which are not from a textbook series. Since many courses inevitably adopt the distinct symbology and format of the text, inexperienced engineering students struggle to transpose symbology from course to course. This often results in difficulty understanding concepts and analyzing basic systems. Integrated courses, crossing traditional course lines, introduce then immediately reinforce fundamental principles without the artificial barriers that accompany new textbooks and new courses.

For instance thermodynamics introduces several forms of the energy equation: closed system approach in terms of energy and energy per unit mass and steady-state control volume approach in terms of energy flow and energy flow per unit mass. Fluid mechanics typically applies the energy equation in terms of head. Many students have difficulty making the connection among these various forms of the energy equation. They fail to realize that each of these forms is an expression of the same basic principle but with different assumptions, different units of measurement, or applied to different systems. Integration of these two subjects would reinforce students' understanding of the basic principle and the various forms in which it might be expressed.

Accreditation Board for Engineering and Technology (ABET).

Most engineering programs are concerned about ABET accreditation. Another advantage that an integrated curriculum offers is extensive support of ABET's Criteria for Accrediting

Engineering Programs. Specifically, this proposal directly improves upon the following from Criterion 3, Program Outcomes and Assessment⁸:

Engineering programs must demonstrate that their graduates have:

- (c) an ability to design a system, component, or process to meet desired needs
- (d) an ability to function on multi-disciplinary teams
- (e) an ability to identify, formulate, and solve engineering problems
- (g) an ability to communicate effectively
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

In addition to this, the integration of curriculum is directly related to Criterion 8, Program Criteria, which states "...graduates have: ...the ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems."

An integration of curriculum better supports several USMA Mechanical Engineering Program Outcomes and Objectives that are listed below.⁹

Program Outcomes:

1. ...ability to...solve mechanical engineering problems.
3. An ability to function professionally...on multidisciplinary teams.
7. ...an understanding of the impact of engineering solutions...in global contexts.

Program Objectives:

1. Solve problems of the Army and the nation in a technologically changing environment using mechanical engineering principles and practices.
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. ...prepare graduates for advanced study in mechanical engineering...and success at top mechanical engineering graduate programs.

ABET focuses on output criteria while institutions determine the method of instruction to support their programs. Integrating the curriculum such that more opportunities for project-based learning exist strengthens any program seeking ABET accreditation.

Project-Based Learning

The advantages of project-based learning are well documented in literature. Building a project, or even developing a paper design, augments simple auditory and visual learning styles with the kinesthetic mode of perception.¹⁰ Projects often stimulate intellectual excitement among students, an emotion that Lowman¹¹ linked directly to teaching effectiveness. For these and other reasons, the current mechanical engineering program includes both hands-on and paper projects in many courses.

The proposed mechanical engineering curriculum uses multidisciplinary projects as the foundation for developing new courses. Instructors introduce projects on the first day of class and include them in the syllabus. These projects vary from year to year. Lesson objectives integrate topics to promote direct theory-to-project application. Possible categories of projects

include course-specific projects, competitions, and large-system projects in which mechanical engineering students work on discipline-specific components as members of a multidisciplinary team.

Further opportunities for multidisciplinary projects may exist by linking related courses from different engineering programs or by integrating engineering program design sequences (this latter option is discussed below, Integrated, Multidisciplinary Design Sequence). These opportunities would allow students to improve their abilities to work together on multidisciplinary projects. This is a very important skill in engineering practice and in the Army. The current program attempts to groom this skill during cadets' senior year capstone design project. However, students often have limited opportunity to work with others outside of their discipline. Too often students try to divide project tasks into very distinct parts as opposed to bringing their diverse skills together to synergistically design the best product. The reason this happens is that their compartmentalized academic program trains them to think of each component of the product falling into a distinct discipline. For example, in designing an autonomous vehicle, students think the mechanical engineers should design the frame and perform the traction analysis, the electrical engineers should select the battery and motor, and the computer scientists should write the code. They usually do not understand how to integrate their efforts so that the computer scientists understand what input the motors need, the electrical engineers select batteries to overcome the resistive forces calculated in the traction analysis, and the mechanical engineers design the frame with room enough to carry the laptop providing the brains for the robot. Integrating courses into a few engineering tracks to offer the opportunity for project-based learning on multidisciplinary teams helps break the paradigm that every task must fall into a specific course taken in the academic program.

Another benefit of a project-based program is a format of instruction that more closely resembles that of a practicing engineer in today's technological world. Instead of reliance on textbook learning and book problems, student learning is primarily project-focused—very similar to the manner that an engineer gains additional knowledge required for a particular project. Another student benefit of this integrated format comes from experience solving multidisciplinary problems. A multidisciplinary problem establishes a systems mindset among students, reinforcing the concept that engineers today often work in interdisciplinary teams. Early introduction and continued exposure to multidisciplinary problems or projects inculcates multidisciplinary, systems thinking.

Bridging the Gap between High School and Graduate School.

Many graduate engineering programs, particularly those involving a thesis option, focus on independent research to support a project. Coursework is often based on specialty topics or selected by the student to support research interests. This pedagogical approach aligns well with engineering practice today. Indeed, many graduate programs offer students the experience of serving as an apprentice engineer. Additionally, some undergraduate programs offer similar experiences. Harvey Mudd College requires its students to complete three Engineering Clinics in which students work in teams on open-ended externally driven design projects.¹²

By contrast, the mechanical engineering program at the USMA is highly structured and compartmentalized, as illustrated in Figure 3. Courses fit neatly into a semester of forty lessons. In this traditional “block” framework, one course introduces concepts while another course using a different text and format builds on the concepts. Additionally, related courses with different textbooks often cover some of the same topics, either in review or in application to a different system. Most students conduct some degree of independent research only as part of the capstone project, which falls principally in the final semester of matriculation. For these reasons a compartmentalized program can be a hurdle to learning, especially in higher levels of the cognitive domain.

FRESHMAN		SOPHOMORE		JUNIOR		SENIOR	
CC	CC	CC	ES	ES	ES	ES	ES
CC	CC	CC	CC	ES	ES	ES	ES
CC	CC	CC	CC	ES	ES	ES	SM
CC	CC	CC	CC	ES	ES	ED	CP
CC	CC	CC	CC	CC	ED	CC	CC
CC	CC	CC	CC	CC	CC	EL	

CC: Core Course ES: Eng. Science ED: Eng. Design
SM: Seminar CP: Capstone EL: Elective

Figure 3: Framework of Current ME Program

The proposed program is built upon integrated “tracks” of courses in lieu of semester “blocks.” Such a framework offers students the opportunity to achieve higher levels of cognitive domain—analysis and synthesis¹⁰—to a greater degree earlier in the curriculum. Ideally, student exposure to these integrated courses begins with the very first engineering course, establishing an integrated systems precedent. Incorporated within a project-based model, this proposed curriculum presents students more opportunities for independent (individual or team-based) research. An outcome of this proposal is a program that better prepares students for both graduate studies and service as a practicing engineer.

Creating a Program Rich in Electives.

One enriching feature of this proposal is creation of more room for electives in the program. Adding elective courses offers students opportunities for greater depth and breadth of study. Depending upon research interests or capstone project, students may choose to conduct an independent study in a very specific technical field or perhaps take a more advanced computer programming or electrical engineering course. Additional elective spaces can also facilitate the integration of emerging technology topics, such as micro-electrical-mechanical systems (MEMS), nanotechnology, bioengineering, acoustics, tribology, or mechatronics. For many of these new electives, opportunities for distance learning are growing.

Integration of the mechanical engineering curriculum also frees electives in other

engineering programs. Several programs at the USMA require courses in mechanical engineering to add breadth and to better prepare students for the Fundamentals of Engineering Examination. An example is the civil engineering majors who take thermodynamics and fluid mechanics from the Mechanical Engineering Division. Curriculum integration would allow civil engineering students to take the first semester of a two-course thermal sciences sequence instead of two separate one-semester courses in thermodynamics and fluid mechanics. Civil engineering applications topics not covered in this one-semester course, such as open channel flow, are covered in the hydrology course taken within the Civil Engineering Division. This specific example also applies to environmental engineering majors. Other programs with similar situations include electrical engineering, nuclear engineering, and engineering management.

PROPOSED CURRICULUM

This proposal calls for the integration of courses having related topics into four different tracks – Engineering Mechanics, Thermal Engineering, Engineering Dynamics and Controls, and Engineering Design and Capstone. Other courses would remain in their current state. The students selecting the General Mechanical Systems Concentration still would take two courses focused on ground vehicles, and the students selecting the Aeronautical Systems Concentration still would take three courses in flight dynamics for fixed wing and rotary wing aircraft. The USMA's core curriculum would remain unchanged. Students would continue to take Engineering Mathematics and Fundamentals of Electrical Engineering.

Integrated Tracks.

The courses that would be included in the various tracks of this proposal are discussed. Because the specific subjects of each track require a great deal more thought and research, only one of the tracks is discussed in more detail as an example. The Engineering Mechanics track would consist of topics from statics, mechanics of materials, and engineering materials. The Thermal Engineering track would include topics from thermodynamics, fluid mechanics, and heat transfer. The Engineering Dynamics and Controls track would consist of topics taken from dynamics, vibration engineering, and dynamic modeling and control. The Engineering Design and Capstone track would integrate topics from introduction to design, mechanical design, and computer-aided design to support the capstone experience.

There have already been efforts at integrating thermodynamics, fluid mechanics, and heat transfer into the field of Thermal Engineering. Two recent texts that integrate these topics are *Thermal-Fluid Sciences*,¹³ by Çengel and Turner and *Introduction to Thermal Systems Engineering: Thermodynamics, Fluid Mechanics, and Heat Transfer*¹⁴ by Moran, Dewitt, Shapiro, and Munson.

As discussed later in this paper, one of the challenges to integration is choosing which topics to include and which to move to an advanced elective. For the Engineering Dynamics and Controls Track, topics that would be included in a two-semester sequence are modeling of mechanical and electrical systems, linearization, conversions between time and frequency domain, response solution for first and second order systems, second order system applications, higher

order systems, control design objectives, root locus, frequency response, and state-space techniques for designing controllers. The details for each of these topics are found in the paper "Integrating Dynamic Systems, Vibration, and Control".¹⁵ Some of the subjects normally taught in a vibrations engineering course that would be omitted from this integrated track are approximate solution methods, normal modes and modal analysis, vibration of continuous systems, and structural or coulomb damping. Examples of topics normally found in a controls course that would be omitted from this integrated track are hydraulic and thermal system modeling.

The proposed integrated tracks shown in Figure 4 provide students an opportunity for greater depth of understanding of related topics currently taught in separate courses. An additional advantage is that any redundancies among the original individual courses can be eliminated. Integration of courses demands that track developers make deliberate choices about topics to include and exclude. Those topics excluded from the track might be offered later in the curriculum through elective courses or other learning options.

COURSE	SEMESTERS		INTEGRATED TRACK	SEMESTERS
Statics	0.5	→	Engineering Mechanics	2
Mechanics of Materials	1			
Engineering Materials	1			
<hr/>				
Vibrations Engineering	1	→	Engineering Dynamics and Controls	2
Dynamics	0.5			
Dynamic Modeling and Control	1			
<hr/>				
Thermodynamics	1	→	Thermal Engineering	2
Fluid Mechanics	1			
Heat Transfer	1			
<hr/>				
Introduction to Design	1	→	Engineering Design and Capstone	3
Mechanical Design	1			
CAD	1			
Capstone	1			

Figure 4: Proposed Integrated Course "Tracks"

One noteworthy highlight of the integrated tracks is shown in the proposed template in Figure 5. Three additional elective spaces are placed in semesters 7 (two electives) and 8 (one elective). As previously stated, the elective spaces allow students to select specialty topics, such as micro-electrical-mechanical systems (MEMS), nanotechnology, bioengineering, acoustics, tribology, or mechatronics, taken at the USMA or other schools through distance learning. Students could also select advanced courses in this or other programs to directly support the capstone project.

CURRENT PROGRAM TEMPLATE FOR GENERAL MECHANICAL SYSTEMS				
SEMESTER 4	SEMESTER 5	SEMESTER 6	SEMESTER 7	SEMESTER 8
Statics and Dynamics	Engineering Materials	Electrical Engineering	Dynamic Modeling and Controls	Mech Systems Capstone
Engineering Math	Mechanics of Materials	CAD	ME Design	Heat Transfer
Core Course	Fluid Mechanics	Intro to Design	Vibration Engineering	ME Seminar
Core Course	Thermodynamics	Mechanical Power Plants	Mech Power Trains	Core Course
Core Course	Core Course	Core Course	Core Course	Core Course
Core Course	Core Course	Core Course	Elective	
PROPOSED PROGRAM TEMPLATE FOR GENERAL MECHANICAL SYSTEMS				
SEMESTER 4	SEMESTER 5	SEMESTER 6	SEMESTER 7	SEMESTER 8
Engineering Mechanics		Automotive Engineering		ME Seminar
Engineering Math	Thermal Engineering		<i>Elective</i>	<i>Elective</i>
Core Course	Engineering Dynamics and Controls		<i>Elective</i>	Core Course
Core Course	Engineering Design, Capstone, and Elective			
Core Course	Electrical Engineering	Core Course	Core Course	Core Course
Core Course	Core Course	Core Course	Elective	

Figure 5: Current and Proposed Program Templates for General Mechanical Systems

BEYOND IMPLEMENTATION: FUTURE POSSIBILITIES

Introduction to Engineering Course.

One of the more exciting possibilities that stems from this curriculum integration is the possibility of adding an Introduction to Engineering course in the curriculum. Currently, the mechanical engineering students at the USMA do not take their first engineering course until the second semester of their sophomore year. They have already declared their major at this point. It would be very beneficial to these students to experience engineering before deciding on a major. Introductory courses have been used at other institutions with success. An example would be the Introduction to Engineering Systems course recently developed at the University of Notre Dame.¹⁶

This Introduction to Engineering course would be part of the USMA's engineering program. Early in the curriculum, all students selecting engineering would take a one-semester course that introduces them to various engineering disciplines through completion of different projects as members of a team. The course would be similar to the USMA's current Invitational Academic Workshop (IAW) held during the summer for high school students. The IAW allows students to explore several different disciplines by completing relatively simple projects with other students. Examples of these projects include constructing a digital clock as an electrical engineering project, creating a Lego vehicle to negotiate a course as a mechanical engineering project, and building a K-nex bridge as a civil engineering project. Upon completion of Introduction to Engineering near the end of their sophomore year, students would then select the particular engineering major.

Including an Introduction to Engineering course early in the curriculum has three distinct advantages. First, students have a much better understanding of what each of the engineering disciplines includes. Many students do not fully understand the difference among mechanical, civil, electrical, and computer engineering. By taking an introductory course, students not only would be able to decide whether they want to be engineers, but also would be able to make an educated decision about which type of engineering to select as a major. Second, this course places multidisciplinary engineering much earlier in the curriculum. Most students do not focus on the important aspect of working within a multidisciplinary team until the capstone design project, if at all. This introductory course sets the precedent for their engineering education by demonstrating that all real-world projects are designed and developed by a team of diverse engineers. Taking the same course with students in different engineering disciplines helps students realize the multidisciplinary nature of projects. Third, a core engineering course introduces project-based learning earlier in the curriculum, the importance of which has already been discussed.

Integrated, Multidisciplinary Design Sequence

The possibility of a future multidisciplinary design track combining several disciplines also exists. Presently, most engineering programs at the USMA offer design in a two-course sequence that is somewhat focused on the specific capstone project on which the cadet will eventually

work. This integrated design concept combines mechanical engineering, electrical engineering, and computer science design sequences. Additional possibilities exist to also incorporate civil engineering, environmental engineering, and systems engineering design sequences.

Many potential benefits to integrating design sequences exist. First and foremost, an integrated design sequence mirrors today's engineering practice. Similar to the rest of this proposal, it provides students a multidisciplinary opportunity early in the curriculum. Second, current design courses are largely project-based with students working on one or more engineering design projects during each semester course. Multidisciplinary sequences could include more complicated designs, especially mechatronics projects. Third, the cadet capstone experience could substantially benefit from an integrated design sequence. Much like the confusing symbology of different courses, each engineering program at the USMA teaches different design methods. For multidisciplinary capstone projects, students from different programs spend time and effort trying to overcome the "language barrier." A multidisciplinary sequence presents the same material in a similar manner to all students, regardless of engineering discipline.

Although the USMA has not yet developed a formal template for a multidisciplinary engineering design track, the Mechanical Engineering Division has considered several features of the sequence. Beginning with an introduction to design course, students in mechanical, electrical and computer engineering programs would be randomly assigned to sections for a three-semester design track. The first course would be built around one or more engineering design projects that require students to work on multidisciplinary teams. This first course would integrate students from the three programs; however, re-sectioning students by program for independent blocks of discipline-specific instruction might be necessary. Approximately two-thirds of this first course would be devoted to in-class instruction, with the remainder of the semester available to students for design teamwork.

Subsequently within this multidisciplinary track, the second and third courses would focus on the capstone project. Students would be sectioned in classrooms with other capstone project team members. The capstone advisor or a faculty member from any applicable program would serve as the instructor. The second course might offer students the option to request instruction on specific or specialty topics pertinent to the particular capstone project, thus placing more of the onus of planning and learning on the student. Formal instruction would be limited to the first half or less of a semester, giving way to at least one and one-half semesters of independent capstone teamwork

CHALLENGES TO INTEGRATION

One of the biggest challenges that an institution encounters when trying to implement this integrated curriculum is satisfying an ABET requirement that states, "The institution must have and enforce policies for the acceptance of transfer students and for the validation of courses taken for credit elsewhere."⁸ For example, if a student transfers into a school having taken thermodynamics but not fluids, what credit does the gaining institution give the transfer student if its offered thermal science course combines these topics? If a student with one semester of

thermal science transfers to an institution that teaches thermodynamics and fluids separately, what credit does the gaining institution award the student and what additional course requirements are necessary? Fortunately, the USMA is in the unique position that every student begins as a freshman. No transfer credits are accepted, however, core course validations are allowed. Cadets must take all courses required in their chosen major.

Another challenge is the amount of work required to restructure the program. The Mechanical Engineering Division recently developed a one-semester thermal science course in support of the three-course mechanical engineering sequence for non-engineering majors.² The five-member development team required two semesters to complete the project. Significant time and effort are required to change the curriculum from its current state to one of complete integration as suggested in this paper. This time factor raises other issues. For example, should the courses be developed and then put on the shelf until all of the courses are developed, or should phased implementation occur?

By far the most difficult part of the process is selecting the topics to include in courses and selecting those topics to omit. Obviously, a two-semester dynamics, vibrations, and controls course does not have sufficient time to address all topics normally taught in the three distinct courses. USMA currently teaches these three subjects in two and a half semesters. Another important consideration is the design content of the curriculum. As new courses are developed, the progression of courses must provide more design as the students progress through the program. The designs should become more and more unconstrained and address other concerns such as ethics and social impact.

Additionally, choice of textbook is an issue. As mentioned previously, Thermal Engineering now has integrated textbooks on the market. Some may argue that these books do not integrate the topics well enough, but rather pull very separate chapters from already existing texts without much change. For other tracks within this proposal, appropriate textbooks are not yet available. As an example, there is no combined dynamics, vibrations, and controls textbook currently on the market.

The Dean's Policy and Operating Memorandum (DPOM) 5-4: Curricular Development and Change provides procedures to implement changes to the curriculum at the USMA. Implementation of curricular changes requires recommendation by the Curriculum Committee to the General Committee for approval. Impacts on other programs and resource requirements are key factors in whether the mechanical engineering program receives approval to integrate its courses. Addition of an Introduction to Engineering course requires a change to all engineering curriculums.

Redesign of the mechanical engineering curriculum to integrate courses and to offer new electives most likely would have to be achievable within the limitations of the current faculty structure, laboratory space, and technician support at USMA. The ability to offer electives in emerging topics in mechanical engineering will depend on the expertise of the faculty and opportunities available for distance learning. Faculty expertise varies from year to year with turnover in rotating faculty.

CONCLUSION

This paper presents a proposal for an integrated, mechanical engineering program at the USMA. The proposal includes an innovative restructuring of courses currently taught in the mechanical engineering program to better reinforce concepts, to promote student team experience, and to expand electives opportunities. Even if approved for implementation, several years of course development and integration lie ahead. The requirements of the unique academic program at USMA—particularly that incoming transfer students must complete the entire 47-month program regardless of previous college experience—make this significant curricular change a viable option. Some features of this proposal may be adaptable to other mechanical engineering programs as an alternative to the traditional “block semester” style. The effectiveness of an integrated curriculum would be assessed through semester feedback. How well students are able to understand concepts, achieve course objectives, and apply their knowledge to follow-on courses and capstone designs will all be assessed based on this feedback. Data can be compared to the feedback that is currently collected at the end of each semester to determine if the integration of courses has had a significant impact. The questions that support the accomplishment of our program outcomes and objectives can also provide valuable feedback over time. Based on the cited advantages, other institutions may want to consider implementing some of the changes proposed.

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