Course Development in Interdisciplinary Controls and Mechatronics

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Abstract - As the future of engineering education emphasizes more interdisciplinary work, one logical starting point for this evolution is for faculty from different academic departments to work together. Engineering educators cannot ignore the real world’s shifting focus to interdisciplinary engineering, and they should adapt as well. Similar to the total engineering process as a team effort, the engineering education process also benefits from excellent communications among a diversity of team members. This paper highlights a classical dynamical modeling and controls course with students from two different disciplines: electrical engineering and mechanical engineering. Faculties from both departments teach every semester. Sections are assigned to individual instructors but all activities are planned jointly. Course administration is the role of a course director and this role alternates between the two departments each semester. Responsibilities throughout the semester are shared between the instructors. This organizational structure is important, allowing the interdisciplinary faculty team to synchronize their efforts, each contributing their individual strengths and resources to promote student learning and faculty development. The approach is being applied to the development of a new course, Mechatronics. This paper provides details that illustrate the structure and benefits of this interdisciplinary administrative model.

Index Terms - Interdisciplinary engineering, multidisciplinary, controls, mechatronics.

INTRODUCTION

Recently the National Academy of Engineering published “Educating the Engineer of 2020”, which mentioned co-teaching, just in time teaching, and multi-disciplinary teaching. Industry and various academic institutions feel that it is vital to integrate engineering education because many systems existing presently are developed by integrated engineering teams [1]. Drexel University (Philadelphia, PA) proposed and was awarded National Science Foundation Funds in 1987 to develop an Enhanced Experience for Engineering Education (E4) [2]. This program integrated students and faculty from all engineering disciplines for the first two years of the student’s engineering education and put them through an intense integration experience. This program was designed to attract students to engineering but its significant attrition rate (an average 60%), is a factor in Drexel University’s decision to stop the program next year. Our approach at the United States Military Academy (USMA) differs from the Drexel model. Instead of integrating the students in the freshman and sophomore years, we are integrating them in the senior year. The advantage is that the students having mastered engineering fundamentals at this point of their education and being somewhat more mature than underclassmen are more able to appreciate the need for an interdisciplinary attitude. Also by taking an interdisciplinary course in the senior year, they tend to develop respect for peers outside of their own discipline.

The analysis and design of feedback systems has drawn several disciplines closer together over the decades. It is not difficult to find a mechanical system that has an electrical analogy and vice versa. This complementary nature of these two disciplines has allowed a single course to evolve concerning the theory and fundamentals of control systems engineering. Requiring the students to see a broader picture across several disciplines also requires the instructors to change their discipline specific practices.

Each of the engineering programs at USMA ensures all engineering graduates take a set of courses that develop their problem solving skills and expose them to technology in society. The academic program, like the other aspects of the USMA environment, is designed to promote development in a wide variety of traditional subjects in the sciences essential to future military service. Two academic departments at USMA, Civil and Mechanical Engineering, and Electrical Engineering and Computer Science, have jointly developed Dynamic Modeling and Control, an interdisciplinary, senior level course of control systems engineering with broad applications to mechanical and electrical systems. In order to create an interdisciplinary engineering experience, the students must know some basic laws and fundamentals of engineering, necessary to engage in practical application of the subject matter. This knowledge comes from several prerequisite courses taught usually during their junior year: Introduction to Electrical Engineering, Engineering Mathematics, and Dynamics. These courses are also taught by different departments and the faculties are single-disciplined.

The course is required for the mechanical engineering major and the electrical engineering major with a robotic systems concentration. Although the course covers many of the same topics as classical controls courses at other
colleges, it is different in some important ways. An interdisciplinary team approach is used in the administration of the course, but each section is taught solely by an individual instructor. Some sections are taught by mechanical engineering faculty, and other sections are taught by electrical engineering faculty. Students from both departments are mixed in every section. Consistency of content and grading from section to section is given much import at USMA and it is the role of a course director to enforce this. Perhaps what most makes the USMA course unique is that the course director function alternates between departments each semester. Various outcomes from the course and insights gained from the instructors will be presented in this paper. Although the course has been taught for several years, this is the first assessment of the structure and administrative model of the course. Assessment of future terms is expected to corroborate the observations presented in this paper.

**BACKGROUND**

The Dynamic Modeling and Control course devotes 3.0 credit hours to engineering topics with 2.0 credit hours allotted to engineering science and 1.0 credit hour to engineering design. The course builds upon the foundation from the basic statics and dynamics course and the basic electrical circuits course. Dynamic Modeling and Control provides the experience and fundamental design knowledge to complete capstone design projects requiring modeling and control design. Presently about 80% of the students taking the course are Mechanical Engineering students and 20% are Electrical Engineering Students.

**Dynamic Modeling and Controls, Percent of Time per Topic**

- **State Space**: 18%
- **Dynamic Modeling**: 18%
- **Time Response**: 8%
- **Stability & Error**: 8%
- **Frequency Response Design**: 25%
- **Root Locus Design**: 25%

*Figure 1: Distribution of time spent on topics*

The course provides an overview of classical control theory as the foundation for control applications in electrical, mechanical, chemical and aeronautical systems. Topics here include dynamic system modeling using Laplace transform, frequency response, root locus methods, and an introduction to state variable methods. Percent coverage of these topics is illustrated in Fig.1. Mathematical models are developed for electrical, mechanical, aeronautical, and other physical control systems. Control systems analysis and design techniques are studied within the context of how each system is physically controlled in practice. Laboratory exercises include feedback design and system identification. Computer design exercises include dynamic modeling and control of various engineering systems.

The course learning objectives are:

1. Model the dynamics of various physical systems that include mechanical and electrical components.
2. Analyze a physical system that utilizes a control system and determine its ability to meet performance specifications for stability, steady-state error, and transient response.
3. Design a controller for a physical system to meet a set of performance specifications using Root Locus, Frequency Response, and State-Space methods.
4. Connect and integrate topics from Thermodynamics, Statics, Dynamics, CAD, Fluids, Vibrations, EE Fundamentals, Circuit Theory, Basic Electronics, Linear System Theory, and/or Signal Representation Techniques.

**INTERDISCIPLINARY TEACHING**

The engineering curriculum at USMA attempts to bring real world experiences for the student, and part of this includes integrating various engineering disciplines. It is highly encouraged to have interdisciplinary senior design teams and projects, because when the students leave the academic environment they are expected to work in diverse teams. This course gives the students an initial step working with other faculty and students. The students take an interdisciplinary course and the faculty must teach so as to demonstrate the value of the subject beyond a specific niche. Engineered systems such as camera, automobile, space shuttle, and robot that integrate the various disciplines make good classroom discussion topics to illustrate the value of an interdisciplinary approach. In the course, students reinforce their discipline-specific knowledge and integrate it with new knowledge and applications. This requires the faculty to understand and have some fluency outside their own discipline.

The collaborative environment allows open discussion between instructors of the two different departments to find better ways to present material that may not be specific to one’s discipline. The quality of instruction improves as the instructors use their discipline-specific strengths to address topics from different backgrounds. At the same time, an instructor confronted with a new or unfamiliar topic can learn and improve in a nonthreatening setting from peer instructors in the other discipline. In general each instructor conducts demonstrations and laboratories for his section regardless of whether the exercise is electrical or mechanical.
in nature, but for the first time the more knowledgeable instructor may give the demonstration to all sections allowing the out-of-discipline instructor to get comfortable. Working together with some creativity, it is quite possible to find different approaches to present material or draw analogies in another discipline. For instance, a mechanical system of masses, springs, and dampers can be represented by an electrical circuit of inductors, capacitors, and resistors that has the same dynamic response. The mathematics to design a controller to meet specifications will be the same, but the students benefit from seeing the analogy of the physical models. This encourages innovation among the instructors to appeal to the different disciplines. Ideally, the students will see the continuities and similarities in different disciplines because the instructors have done their work to integrate the material.

The multi-department administrative structure allows for sharing physical resources. Recently a mechanical engineer instructor demonstrated frequency response design with equipment owned by the mechanical engineering department. The sound and visual effects heightened the impact of the demonstration. The students appreciated the tie between classroom theory and a system they are all familiar with: their automobiles. The electrical engineering instructor did not have the same equipment in his department. Had the course been taught by a single department, numerous opportunities like this would be passed.

Inherent in a course taught by multiple instructors is the obvious advantage of the shared workload for problem development, labs, grading, tests, and student advising. The instructor team sets the lessons’ content to meet the course objectives, determines texts, videos, demonstrations, and supplemental materials. It is essential that the strengths and weaknesses of the individual instructors are assessed in order to share the course workload. The flexible, collaborative environment allows for individuals to perform at their best. The electrical engineering instructor can more easily develop an electrical engineering problem for homework or a test than the mechanical engineer and vice-versa. By dividing the instructor workload, the team operates more efficiently.

Perhaps an overlooked advantage to the interdisciplinary team teaching structure is that this organization fosters faculty development. USMA faculty who have taught Dynamic Modeling and Control observe that the close collaboration required to deliver quality teaching in all sections of the course leads naturally to faculty learning outside their own discipline. For the authors of this paper, this experience is one of the most rewarding in a teaching career. Constant dialogue between instructors of the two disciplines allows each to know what the students should know or retain. The mechanical engineering instructor learns the subjects and depth covered in the electrical engineering course and vice-versa. This collaboration allows the instructor to progress the material in a lesson without having to cover basic knowledge. Instructors can also draw on certain students’ strengths during classroom discussions. Instructors are able to address learning techniques and study skills when familiar with the other discipline’s basic knowledge.

It is the role of the course director to report to department leadership about the course, set course schedules, ensure that all instructors are aware of upcoming course material, and delegate tasks to the instructors. The instructors understand that the course director role alternates between the departments, so instructors find it advantageous to all concerned to assist in course administration. This setup helps keep the instructors from the different departments engaged in the course. Additionally, the change motivates the instructors to keep course notes current and grade consistently.

**APPLYING THE MODEL TO OTHER COURSES**

The interdisciplinary structure of Dynamic Modeling and Control has been so successful that is being applied to a new course, Mechatronics. Dynamic Modeling and Control is a prerequisite for Mechatronics and typically students take both courses in the senior year. One of the course projects, an unmanned ground vehicle, shown in Fig. 2, exemplifies

![Figure 2: USMA Cadet working on an unmanned vehicle project in Mechatronics.](image)
Mechatronics. Engineering majors in the mechatronics track take Engineering majors in the robotics track and Mechanical Engineering majors in the mechatronics track take Mechatronics.

Not only is Mechatronics taught by an interdisciplinary team, but it is being developed by both departments as well. All the lessons learned from teaching Dynamic Modeling and Control are being applied to develop content that is teachable to students from both disciplines. Mechatronics is currently running for the second time (Spring 2008).

Mechatronics is interdisciplinary to even a greater degree than Dynamic Modeling and Control since it is team-taught: there are two instructors, one electrical and one mechanical. The responsibility for course development and classroom delivery is divided according to logical blocks of instruction during the term. For example, the electrical engineering instructor develops content (lesson material, homeworks, labs, and exams) for the direct digital control block while the mechanical engineering instructor develops the material for thermal systems block. The content is vetted through the out-of-discipline instructor leading to improved presentation; a process that is not available for single-discipline courses.

As with Dynamic Modeling and Control, department resources are shared. Laboratory experiments are conducted in the electrical engineering department facility which has the necessary tools and bench instruments while some of the experiment hardware is fabricated by the mechanical engineering department technicians.

The Mechatronics course is new, and the benefits of the course structure and interdisciplinary course model are being assessed.

CONTRIBUTIONS AND FUTURE WORK

Dynamic Modeling and Control is about generalizing control design methods for electrical systems, mechanical systems, and systems in other disciplines. The Mechatronics course is about integrating the electrical, mechanical, computer science, and control design disciplines throughout the process of designing smart systems. In both courses the multidisciplinary approach works because the course content itself is multidisciplinary. Describing the advantages and limitations of this teaching endeavor provides guidelines to implement the method at other institutions. Also, the initiative could stimulate faculty and students to approach other departments to conduct interdisciplinary research and conduct joint and collaborative design projects. Multidisciplinary projects are highly encouraged by the leadership of the academic departments and also are very relevant and marketable for the student’s future positions.

Our short term goals are to evaluate existing course work and integrate more applications and demonstrations that could make an immediate impact on student learning. We also intend to use the lessons learned to encourage multidisciplinary research projects and to stimulate additional interest among faculty and students of other departments to consider Dynamic Modeling and Control as a model for interdisciplinary courses. This will better prepare our future engineers to face the multidisciplinary systems and problems that exist today.

CONCLUSIONS

The advantages and disadvantages of an interdisciplinary course extend beyond course content of both electrical engineering and mechanical engineering programs. The benefits of sharing applied engineering and math, dealing with various engineering systems, learning through generalization of problems and applying control models to different disciplines provide not only enthusiasm among students and faculty, but they also sustain program goals sought by the different disciplines as well as the vision of a multidisciplinary engineering study. The approach has been so successful at the United States Military Academy that it is being applied to the new course, Mechatronics. The methods profiled in this report can be mirrored elsewhere to facilitate collaboration between various engineering departments and disciplines. Nevertheless, teaching an interdisciplinary course requires a committed, motivated faculty who are creative and willing to change. The authors find that working as an interdisciplinary team to teach interdisciplinary subjects provides rewards for both faculty and students well worth the additional effort required.

REFERENCES


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