AC 2009-461: REDESIGN OF A DYNAMIC MODELING AND CONTROL COURSE FOR MULTIDISCIPLINARY ENGINEERING

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Abstract

Multidisciplinary engineering education experiences many challenges in its growth, but these changes also present new possibilities. Engineering education has recently emphasized more multidisciplinary work as graduates are expected to perform on multidisciplinary engineering teams and have some working knowledge in other engineering disciplines. A reasonable progression for this aim in multidisciplinary work is with the faculty. The need for multidisciplinary educators to work together as a team both in and out of the classroom requires adaptation from a traditional, single discipline focus. The multidisciplinary engineering education process at the United States Military Academy (USMA) is a coherent effort with excellent communications between faculties from different departments. This paper highlights a classical dynamical modeling and controls course with students and instructors from different departments: electrical engineering, mechanical engineering, and chemical engineering. Recent creation of a chemical engineering curriculum necessitated incorporation of controls engineering coursework in their program of study. An existing dynamic modeling and controls course existed between two departments: electrical engineering and mechanical engineering. With the introduction of chemical engineers in the course, the chemical engineering specific lessons are taught by a chemical engineering instructor. This organizational structure is important, allowing the multidisciplinary faculty team to synchronize their efforts, bringing their individual strengths and resources together for the course to promote student learning. The instructors engage in meaningful dialogue concerning their assignments, lesson preparations, laboratory exercises, and their results. The information flow between instructors from different departments encourages faculty learning by pushing the instructors beyond their own discipline. This paper illustrates some of the course details employed between three engineering departments to advance and enrich a multidisciplinary controls engineering course. Advantages to empowering a multidisciplinary faculty are also described. The techniques described allow the students to benefit from the work of a multidisciplinary faculty team and enrich the students' understanding by bringing in real world projects and examples.

Introduction

In 2005 the National Academy of Engineering in "Educating the Engineer of 2020," stated many ideas of co-teaching, just in time teaching, and multi-disciplinary teaching.[1] Government, private industry and various academic institutions feel that it is important to integrate engineering because most systems existing presently are developed with integrated engineering teams. Discipline specific organizations have identified the need for their disciplines to cross boundaries. In the "2028 Vision for Mechanical Engineering,' from ASME, the report draws attention to the complexity of advanced technologies and the multiple scales at which systems interact. Both will require engineers to collaborate in developing multidisciplinary solutions.[2] In "Vision 2020: Reaction Engineering Roadmap," from AIChE, participants acknowledged the need for multidisciplinary education to handle highly integrated knowledge and suggested incentives and resources for development of interdisciplinary courses.[3] Drexel University (Philadelphia, PA) proposed and was awarded National Science Foundation funds in 1987 to develop the program "Enhanced Experience for Engineering Education (E4)."[4] 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 many more students to engineering and has retained many students who selected an engineering major. However, our method is different. Instead of integrating the students in the freshman and sophomore years, we are integrating them in the senior year. One advantage is that the students are much more developed in their engineering discipline, and we are adding to that knowledge base.

Integral to the education of its engineering majors, USMA ensures that all of its engineering graduates take a set of engineering courses to develop their problem solving skills and expose them to technology in society. The academic program, like the other aspects of the school's environment, is designed to promote development in a wide variety of traditional subjects in the sciences essential to future professional service. Analysis and design of feedback systems have benefits in many dynamic systems, attracting several disciplines closer together. It is not difficult to find a mechanical system that has an electrical analogy and vice versa. This natural equivalence between these two disciplines has allowed a single course to evolve concerning the theory and fundamentals of control systems engineering. Similarly, chemical engineering relies on practical use of control systems for process and reaction manipulation. Requiring the students to see a broader picture across several disciplines also requires the instructors to change their discipline specific practices.

Three departments at USMA have fostered a multidisciplinary, senior level course of control systems engineering with broad applications to mechanical, electrical, and chemical systems. In order to create a multidisciplinary 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 engineering 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.

This paper focuses on and examines the course, Dynamic Modeling and Control, required at USMA of all mechanical and chemical engineers and for the electrical engineers that are in the robotics concentration. Although the course uses a standard textbook and covers many classical and modern control topics, it is different in some ways from a typical engineering course. The course is taught with students from the three disciplines mixed within each section. Instructors are from three different departments and use a team-teaching approach to administer, teach, and improve the interdisciplinary course. Team-teaching usually involves discipline specific instructors teaching their area of expertise to the students. This course differs in that the chemical engineering instructor teaches the chemical engineering lessons and each mechanical and electrical engineering instructor, regardless of background, teaches all remaining lessons to his section. Each section is mixed with mechanical, electrical, and chemical engineering students. On the course administration level, perhaps the most obvious difference is that the course director changes each semester between the electrical and mechanical instructors. Additionally, various outcomes from the course and insights gained from the instructors are presented. Although the course has been taught for several years focused on the mechanical and electrical students, this is the first time to assess the effectiveness of recent changes to appeal to the chemical engineers. Future terms are expected to corroborate the material 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 foundations from the basic engineering mechanics course in statics and dynamics, and the basic electrical engineering course covering electrical circuits and components. The course provides the background, experience, and fundamental design knowledge to complete capstone design projects requiring dynamic modeling and control expertise. The course is multidisciplinary and is conducted as a joint offering with the Department of Electrical Engineering and Computer Science and the Department of Civil and Mechanical Engineering.

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 system modeling using Laplace transform, frequency domain, and state variable methods. Mathematical models are developed for various systems to include electrical, mechanical, aeronautical, and chemical 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:

a. Model the dynamics of various physical systems that include mechanical, electrical, and chemical components.
b. 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.
c. Design a controller for a physical system to meet a set of performance specifications using root locus, frequency response, and state-space methods.
d. Demonstrate applications of control theory to chemical, electrical, and mechanical engineering problems.

In the last three academic years, enrollment of chemical engineering students due to a revised curriculum has presented the opportunity to investigate and suggest improvements. Presently about 64% of the students taking the course are mechanical engineering students, 23% are electrical engineering students, and 13% are chemical engineering students. Table 1 below correlates the electrical engineering program outcomes to the course content using the following scale:

1	2	3	4	5
No contribution	Small contribution	Average contribution	Large contribution	Very large contribution

Table 1. Relationship of Course to Electrical Engineering Program Outcome

ELECTRICAL ENGINEERING PROGRAM OUTCOMES	COURSE DIRECTOR ASSESSMENT
1. Apply knowledge of mathematics, probability, statistics, physical science, engineering, and computer science to the solution of problems. [ABET Criterion 3 Outcome (a)]	4.5
2. Identify, formulate, and solve electrical engineering problems. [ABET Criterion 3 Outcome (e)]	4
3. Apply techniques, simulations, information and computing technology, and disciplinary knowledge in solving engineering problems. [ABET Criterion 3 Outcome (k)]	4
4. Design and conduct experiments to collect, analyze, and interpret data with modern engineering tools and techniques. [ABET Criterion 3 Outcomes (b) and (k)]	4
5. Communicate solutions clearly, both orally and in writing. [ABET Criterion 3 Outcome (g)]	4
6. Work effectively in diverse teams. [ABET Criterion 3 Outcome (d)]	3
7. Apply professional and ethical considerations to engineering problems. [ABET Criterion 3 Outcome (f)]	3
8. Incorporate understanding and knowledge of societal, global and other contemporary issues in the development of engineering solutions that meet realistic constraints. [ABET Criterion 3 Outcomes (c), (h) and (k)]	4
9. Demonstrate the ability to learn on their own. [ABET Criterion 3 Outcome (i)]	3

The Mechanical and Chemical Engineering program outcomes, which are not shown here, have similar overlap with ABET Criterion 3 a-k outcomes.

Advantages

The engineering curriculum at USMA attempts to bring real world experiences to the students, and part of this includes integrating various engineering disciplines. Faculty members encourage students 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 to working with other faculty and students, which is a major advantage in the structure of the course. The students are subjected to a multidisciplinary course and the faculty must portray it as a subject with value beyond a specific application. This integration of teaching will bring various engineering subjects together as most current systems are a combination of engineering disciplines such as a camera, automobile, robot, and chemical process. In the course, students from three distinct engineering fields reinforce their discipline specific knowledge and integrate it with new knowledge and applications. This requires the faculty to understand and have some fluency in the other disciplines. For example, each instructor conducts laboratories for his sections, regardless if the laboratory exercise is electrical and the instructor is a mechanical engineer. Unlike some demonstrations in other engineering classes, sometimes a specific instructor or technician, familiar with the equipment, must give the demonstration to all students taking the course.

The Academy operates in a very collaborative environment, allowing open discussion between instructors of the different departments to improve methods 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. It is relatively easy to find a different approach to present material or draw an analogy in another discipline. For instance, an electrical system with inductors, capacitors and resistors can be represented with a mechanical system or chemical process that includes fluid flow, tanks, and valves. The mathematics to design a controller to meet specifications will be the same, but the students benefit from seeing the similarities in the different 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 if the instructors have done their work to integrate and present the material.

Perhaps an overlooked advantage to the interdisciplinary team teaching structure is that this organization allows an instructor to readily build upon student knowledge or a lecture presented in the other discipline. Constant dialogue between instructors of the different departments allows each to know what the students should know or retain. There are certain topics that electrical engineers know from their previous classes, and certain subjects all students should know from the required electrical engineering course. Rather than trying to determine the basic electrical engineering knowledge of the students, the mechanical engineering instructor knows the subjects and depth covered in the electrical engineering course. This collaboration allows the instructor to progress through 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. For instance, in a recent discussion of second order time response, electrical and mechanical examples were numerous. However, chemical engineering students were familiar with a basic chemical reaction that initially results in a different color and pH balance until steady state is reached. This example has become the primary example for chemical engineering students to relate second order parameters.

Inherent in a course taught by multiple instructors is the obvious advantage of the shared responsibility for lesson development. The instructor team sets the lessons' content to meet the course objectives, determines texts, videos, demonstrations, and supplemental materials. The individual instructors can use their initiative and department resources to develop or refine demonstrations and videos for the teaching team. It is essential that the strengths and weaknesses of the individual instructors are assessed in order to share duties. The flexible, collaborative environment allows for individuals to perform at their best. Using discipline specific equipment, each instructor can develop demonstrations that appeal to their disciplines (i.e. the chemical engineer can develop a chemical engineering demonstration), so the students see the same control design process and mathematics applied to different fields. Recently, for a lesson on chemical process modeling, the chemical engineering instructor developed a demonstration with sound and visual effects that all the students could relate to their basic knowledge of other dynamic systems. The students appreciated the demonstration and had something to which they could relate future classes on controller design. The mechanical engineer instructor did not have the same equipment in his department. Had the course been taught by one department or the other, numerous opportunities like this would be passed. The instructor team operates more effectively with open collaboration. Since students come from all three departments, the diversity is advantageous to all concerned and keeps the instructors from the different departments engaged in the course. Additionally, the mixture of students also motivates the instructors to keep course notes current and consistent. The students seem to socialize within their disciplines for class preparation and assignments. Since they compare notes between instructors and help each other, the instructors are basically being watched by other students outside of the classroom. This heightens the instructors' awareness to be consistent and up to date.

Challenges

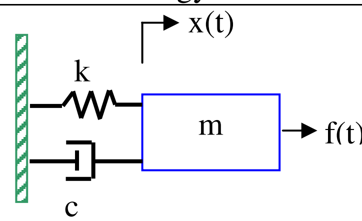
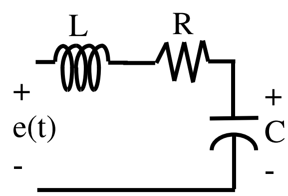
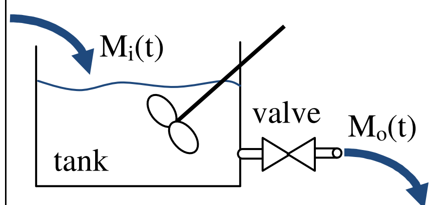
It is well documented in general literature on interdisciplinary teaching that the greatest hurdle for the instructors is the time and energy required to work as a team.[5-7] In this controls engineering course with application to electrical, mechanical, and chemical engineering, the instructors agree that deliberate time management and planning are essential. Scheduling meetings between faculties of three different departments is more difficult, but a committed teaching team can make it work.

First, appealing to all disciplines requires understanding all of the students' engineering backgrounds. This may require some standardization of the lesson material on which the instructors should agree. For example, many of the concepts in control engineering such as stability and transient response are easily demonstrated and visualized with mechanical engineering examples. Table 2 below shows equivalent analogies for transient response for the three different types of students.

Drawing analogies for the other disciplines can sometimes test the instructors. Knowing what or how another instructor presents the material and expects the students to learn ensures some standardization but also ensures homework and tests are fair and relevant. Nonetheless, multidisciplinary teaching takes additional time to understand another discipline. It also takes deliberate effort and openness for the instructors to balance the demonstrations and the use of example applications.

Laboratories are the most difficult area for concurrence between instructors, and are being revised. Similar to the demonstrations, they require much time to ensure all instructors are familiar with the equipment and know the end state of the exercise. The current laboratory equipment employs various electromechanical units and devices as examples of systems to examine. These units are designed for specific controls applications, such as first and second order system parameters, proportional-derivative controller design, and frequency response controller design. However, since most students are taking controls for the first time, the subject and equipment are not readily intuitive. These lab setups are used to emulate generic systems so sometimes it is difficult for the students to relate between lab setups, mathematical equations and actual systems. However, these lab setups are still used due to the flexibility of electronic components, and mechanical laboratory equipment was rarely used. Chemical engineering specific labs are still being developed for the course. The use of electronic equipment causes some initial apprehension with the mechanical and chemical engineers, for both instructor and students. However, part of the experience for both instructors and students was to apply some of the course content to different disciplines.

Table 2: Transient Response Analogies

Engineering	Word Analogy	Picture Analogy
Mechanical	Time for mass to reach final displacement	
Electrical	Time for voltage across capacitor to reach final value	
Chemical	Time for output concentration in the well mixed vessel to reach final (steady-state) value	

Expected Outcomes and Assessment

This course is primarily a lecture based course that attempts to cover a range of applications in mechanical, electrical, and chemical engineering. The course starts by modeling subject or discipline specific systems such as electrical, mechanical, chemical, and electromechanical. The course advances to generalizing each system and developing various methodologies to treat each system in a similar fashion. This is similar to the pedagogy some educators use in classes, where a specific example is used to generalize a problem solving method. Although the instructors come from different backgrounds, they generalize the teaching to motivate and educate a body of multidisciplinary students.

One of the instructors' goals was to assess the effectiveness of the interdisciplinary faculty structure. A look at the course feedback data from recent students taking the Dynamic Modeling and Control course shows some interesting and encouraging results. For the most part, the students agree that the course is a positive experience for them and is better than other single discipline courses. Although different instructors taught the course over the academic year, individual instructor assessments were very similar, so the overall course results are presented. Particular ratings that are addressed in the discussion are indicated on the graphs. The following scale (Table 3) was used for the students' survey:

Table 3: Assessment Scale

1	2	3	4	5
strongly disagree	disagree	neutral	agree	strongly agree

The following assessments address the objective ratings above. Student comments and discussion on the student surveys reinforce their overall ratings. Additionally, the rating scale is a normal set of responses used at USMA for student surveys. Students and faculty alike are familiar with the same standard set of responses and their interpretation.

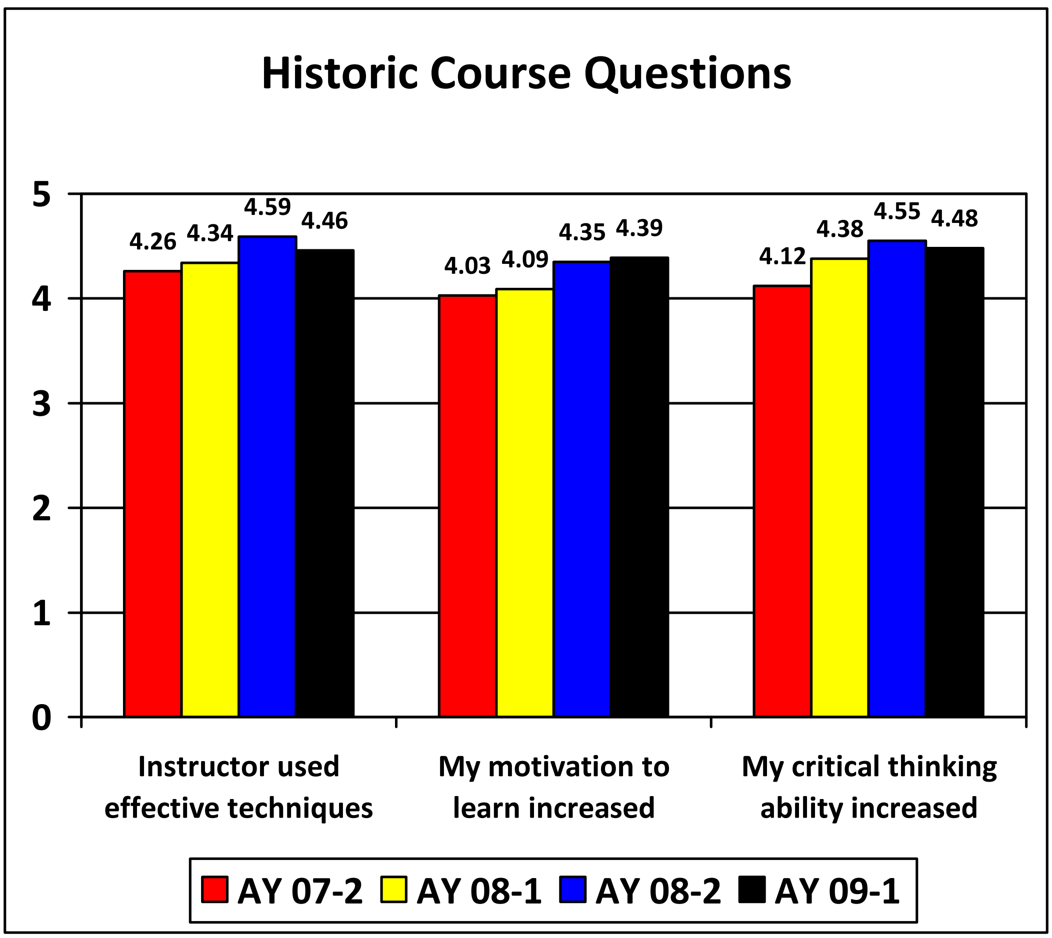


Figure 1. Course Survey Questions

A positive trend can be seen from Figure 1, and averages (not shown) were higher than institutional norms for single discipline courses. Students felt effective techniques were used in the course which resulted in a high average. The collaborative environment among the faculty team lends to better instruction and techniques than teaching the material with a single instructor's limited insight to the broad material application. Likewise, students felt more motivated to learn since the material was applicable in several areas. The engineering students could see the relationships among different fields. One student commented, "The instructor had a great wealth of knowledge about the material covered. He was always willing to spend extra time to make sure that everybody understood the information." One of the most significant developments was that the students felt an increase in their critical thinking aptitude. Gaining self-assurance in their ability to work with or understand another discipline in some depth, the students were more comfortable with the challenge.

Using the same scale presented in Table 3, Figure 2 shows that over three semesters of assessing course objectives, there is very good agreement on students' ability to apply control theory to mechanical, electrical, and chemical systems. One benefit of relating the material to all three engineering disciplines is that a larger number of students may retain the material longer than if the material was taught from just one of the disciplines. Learning styles do not make as much difference as the student's prior knowledge, intelligence, and motivation.[7] Again, the course has been taught for several years. We feel the multi-department faculty model and structure of the course are advantages and are in the process of assessing this organization.

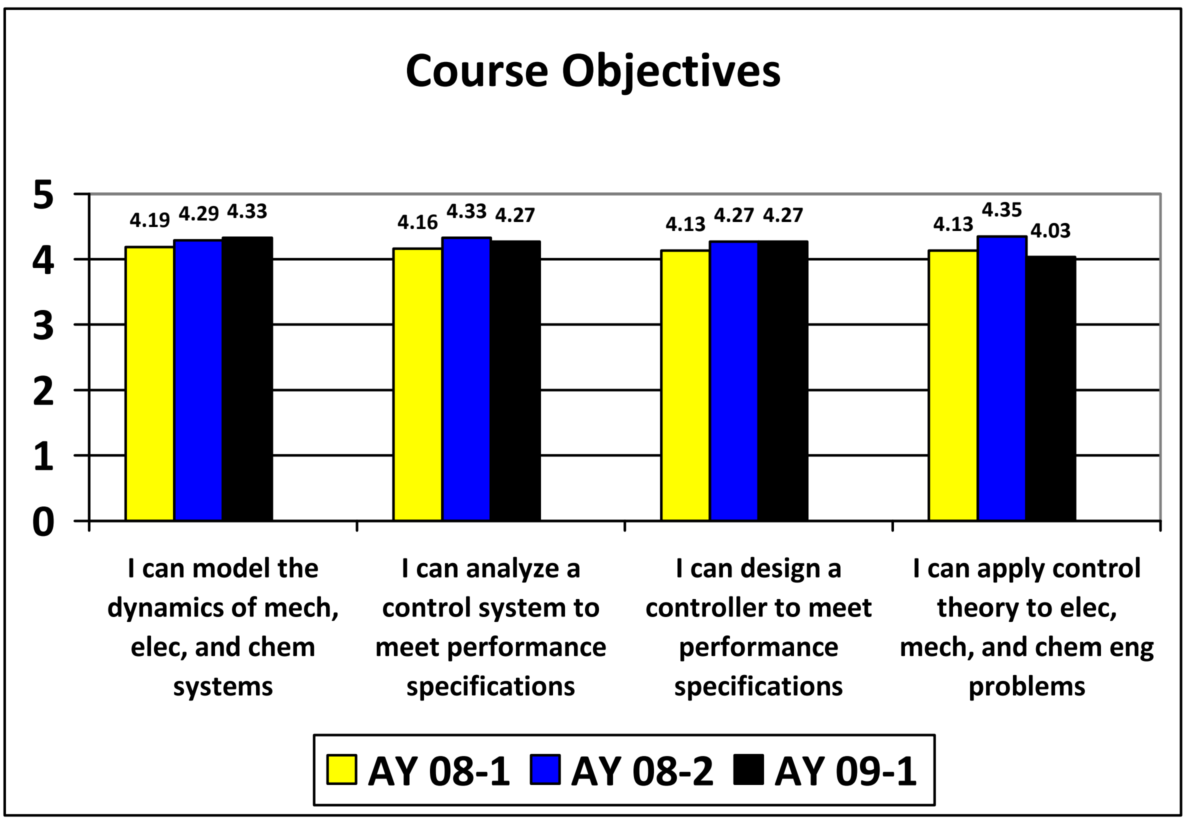


Figure 2. Course Objectives Survey Questions

Chemical Engineering Changes

In the spring of 2007, chemical engineering students began taking the Controls course, originally developed for the mechanical and some electrical engineering students. Course feedback from the chemical engineering students showed they perceived the course as irrelevant to their major. New instructors injected chemical engineering topics and problems in the course to appeal to these students. As part of the annual program assessment, chemical engineering students complete surveys, using the previously mentioned assessment scale, relating their chemical engineering program outcomes, essentially similar to the ABET a-k. The survey questions are listed in the Appendix, and the results are in Figure 3.

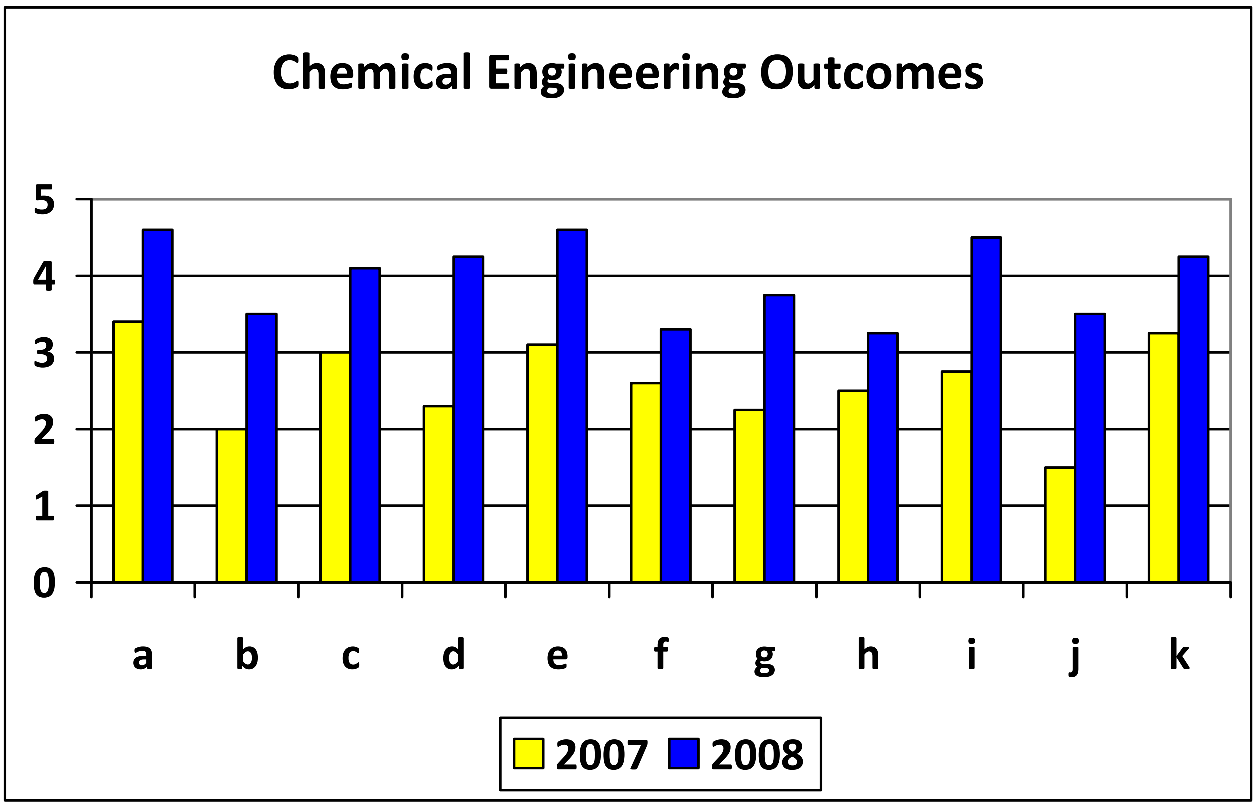


Figure 3. Chemical Engineering Program Outcomes

The changes shown in Figure 3 are a major improvement in the chemical engineering program. The authors acknowledge that the Controls Engineering course is only one course in the chemical engineering curriculum but, based on comments and student surveys, the course contributed to the positive experience of the chemical engineering students. A particularly strong increase is seen in question d, "This course has improved my ability to function on multidisciplinary teams. This result is consistent with other quantitative results for graded embedded indicators in the course.

Contributions and Future Work

In addition to the observations of teaching a multidisciplinary course regarding different types of systems and integrating systems to apply controllers, describing the advantages and limitations of this teaching initiative and endeavor provides guidelines to develop and implement other academic courses. Multidisciplinary engineering courses could stimulate faculty and students to approach other departments to conduct multidisciplinary research and conduct joint and collaborative design projects. Multidisciplinary projects are also highly encouraged from the departments but also help the student become more knowledgeable and valuable in their future positions.

Our short term goals were to evaluate the existing course work and integrate more applications and demonstrations that could make an immediate impact to the students' learning. We intend to use the results and information to stimulate additional interest in other departments, faculty, and students to further study dynamic modeling and controls and to encourage multidisciplinary research projects. This will better prepare our future engineers to face the multidisciplinary systems and problems that exist today.[1-3]

Conclusion

The advantages, challenges, and assessment of a multidisciplinary course experience extend beyond course content of electrical, mechanical, and chemical engineering programs. The benefits of sharing applied engineering and math, dealing with various dynamic engineering systems, learning through generalization of problems and applying control models to different disciplines provide enthusiasm among students and faculty. These benefits, gained from committed faculty members working as a team, support program goals sought by the different disciplines as well as the vision of a multidisciplinary engineering study. The course model described in this report can be emulated elsewhere to pave partnerships between various engineering departments and disciplines. Nevertheless, teaching an interdisciplinary course requires a committed, motivated faculty who are creative and willing to change. Cultivating a multidisciplinary course such as Dynamic Modeling and Control is a growing experience for the faculty as well as the students, but the rewards are worth the additional time required to make it interesting and relevant to the students.

Acknowledgement

The views expressed herein are those of the authors and do not purport to reflect the position of the USMA.

Bibliography

1. National Academy of Sciences, "Educating the Engineer of 2020: Adapting Engineering Education to the New Century," National Academies Press, Washington, D.C., 2005.

2. American Society of Mechanical Engineers, “2028 Vision for Mechanical Engineering,” ASME, New York, NY, July 2008.
3. American Institute of Chemical Engineers, “2020 Vision: Reaction Engineering Roadmap,” AIChE, New York, NY, 2001.
4. Meyers, C. and Ernst, E., “NSF 95-65 Restructuring Engineering Education: A Focus on Change”, NSF, Washington, D.C. 1995.
5. Davis, James R. Interdisciplinary Courses and Team Teaching. Phoenix: American Council on Education / Oryx Press Series on Higher Education, 1997.
6. Goetz, Karin. “Perspectives on Team Teaching.” EGallery. Vol. 1, No. 4., August 2000. http://www.ucalgary.ca/~egallery/goetz.html
7. McKeachie, W. J., Pintrich, P. R., and Lin, Y-G. "Teaching Learning Strategies." Educational Psychologist, 20(3), 153-160. 1985.

Appendix – Chemical Engineering Student Survey Questions

a. This course has improved my ability to apply knowledge of mathematics, science, and engineering.

b. This course has improved my ability to design and conduct experiments, as well as analyze and interpret data.

c. This course has improved my understanding of how to design a system, a component of a system, or a process to meet desired needs within economic, environmental, social, political, ethical, health and safety, manufacturing, and sustainability constraints.

d. This course has improved my ability to function on multidisciplinary teams.

e. This course has improved my ability to identify, formulate, and solve engineering problems.

f. As a result of this course, my understanding of professional and ethical responsibilities has improved.

g. This course has helped me to communicate more effectively.

h. This course has improved my understanding of the impact of engineering solutions in a global economic, environmental, and societal context.

i. This course has helped me recognize the need and develop the skills required for life-long learning.

j. This course has increased my knowledge of contemporary chemical engineering issues.

k. This course has improved my ability to use techniques, skills, and modern engineering tools necessary for engineering practice.