Session 2266

Restructuring the Undergraduate Curriculum of the Mechanical Engineering and Applied Mechanics Department at The University of Michigan

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Abstract

Recent changes in the undergraduate program of the Mechanical Engineering and Applied Mechanics (MEAM) Department at the University of Michigan, Ann Arbor are discussed. The undergraduate curriculum has been modified to emphasize communication skills, teamwork, and hands-on experiences while retaining a strong core of engineering science instruction. The motivations for these changes are presented and the status of the program is discussed.

Introduction

Engineering education has evolved considerably during the last few decades. But the fundamental premise that engineering education should provide students with the ability to solve engineering problems as an exercise in applied sciences has not changed. This notion has, however, come under increasing scrutiny in the last several years, and a number of educators, employers and government officials have called for extensive changes in the undergraduate engineering curriculum (1). Indeed, society at large is demanding that universities evaluate and justify the cost and benefits of undergraduate education.

The faculty of the Mechanical Engineering and Applied Mechanics (MEAM) department of the University of Michigan, Ann Arbor, has conducted a review of the standard program in mechanical engineering. In the beginning of 1992, the chairman of MEAM appointed an Undergraduate Curriculum Review Committee to evaluate the status of the undergraduate program and recommend changes, if necessary. While the program had been incrementally evolving to meet new demands and to take advantage of new opportunities, these changes had generally been on the course level. The committee was charged with examining the undergraduate curriculum as a whole and making recommendations. In this paper, conclusions of our review are presented and the

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significant modifications of the undergraduate mechanical engineering curriculum currently taking place are described.

Review Process

The Undergraduate Curriculum Review Committee consisted of three tenured faculty members, two undergraduate student members, and a former graduate of the department. The committee began with extensive data gathering, including surveys of alumni and students, information about other programs in the United States, and consultations with the faculty and the Department External Advisory Board. An alumni survey was carried out during the winter term of 1993. Student surveys were conducted at the end of fall term 1992 and in the winter term 1993. The student surveys were distributed at meetings of the various student societies in 1992 and in the senior design class in 1993. The latter proved to be highly effective and resulted in nearly 100% return rate. The responses where, however, nearly identical between the two terms.

The alumni survey consisted of a questionnaire created in consultation with a staff person from the Engineering College that was distributed to the classes of 1987, 1982 and 1972 (2). The survey was designed to provide answers to the following questions:

- What are our graduates doing?
- What skills do they need?
- How have we prepared them?

Of 500 surveys sent out, 180 were returned for a (relatively high) 35% return rate. The survey showed that of those responding, over two thirds have an advanced degree or were working on one. All are employed or attending school. Most are currently working for large companies with over 1000 employees, and a large number had worked for only a small number of companies (one or two) during their careers. Somewhat interestingly, this number was only slightly higher for those who graduated in 1972 than for those who graduated in 1982. The largest group works for automotive related industries or services, which is not surprising considering the economy of the state of Michigan. Overall, our graduates (or at least those who responded) are a successful group. Over a third of the senior alumni are in managerial positions, and over 20% are corporate executive officers, presidents, or vice presidents. Over one third of the most junior alumni describe themselves as designers and product development engineers. The breakdown of respondents by their career level is presented in Table 1.

Although the survey did not attempt to map the employment and career paths of the alumni, a model can be inferred: a typical graduate of MEAM starts as a design engineer or product development engineer and then moves into a managerial position within the same (or comparable) company. This model seems to account for the opinions expressed by the respondents when asked to rank the importance of specific skills to their professional lives. We divided this part of the questionnaire into two categories: skills learned in specific MEAM courses and other skills needed for professional development; a partial summary of the responses is shown in Table 2. The alumni were asked not only to rank the importance of each skill, but also to rate how well MEAM and/or the College prepared them in that particular area. Although the two scales are not directly comparable, the results show clearly that the majority of the respondents do not feel the University prepares them well in the areas that are most important to them. These include interpersonal skills and technical communications, understanding social and economic factors that affect their work, design and creativity, and manufacturing. They do feel, however, that the University has prepared them well in many of the engineering sciences as well as in mathematics and physics. These results must be interpreted with some care since graduates are going to feel more strongly the need for skills where they have had little preparation, and have less appreciation for knowledge that has become second nature. Nevertheless, if there is a shortcoming in the education offered by the University, it is not in the basic science and engineering courses but in the preparation of the more "human" aspect of engineering. These sentiments were also reflected in the responses to the open ended questions.

Where our graduates work

Industry

Graduation Year	1972	1982	1987	Total
Aerospace or related	2.3%	10.0%	4.5%	6.2%
Automotive or related	41.9%	32.9%	37.0%	37.1%
Chemical	4.7%	1.4%	1.5%	2.2%
Computer (hardware/software)	7.0%	14.2%	9.0%	10.1%
Consumer products	7.0%	5.7%	7.5%	6.7%
Government	2.3%	2.9%	1.5%	2.2%
Petroleum	2.3%	2.9%	4.5%	3.4%
Public utility	7.0%	4.3%	0.0%	3.4%
University or college	2.3%	5.7%	6.0%	5.1%

Occupational Position

Graduation Year:	1972	1982	1987	Total
Designer	7.0%	7.1%	10.4%	8.4%
Graduate Student	0.0%	2.9%	7.0%	3.4%
Manager of Technical Staff	30.2%	17.1%	4.5%	15.5%
Product Development Eng.	7.0%	20.0%	23.9%	18.4%

Professional Level

Graduation Year:	1972	1982	1987	Total
Supervisor	14.0%	11.4%	7.5%	8.4%
Mid-level manager	14.0%	18.6%	3.0%	11.7%
Senior technical staff/Chief Eng.	16.3%	21.4%	14.9%	17.9%
Director project/team/group	20.9%	20.0%	18.0%	19.6%
Vice President	9.3%	0.0%	0.0%	2.2%
President	9.3%	2.9%	0.0%	3.4%
Corporate Executive Officer	2.3%	1.4%	0.0%	1.1%
Faculty	4.7%	2.9%	0.0%	2.2%

Table 1. A breakdown of survey results of MEAM’s graduates by industry, position, and professional level.

Alumni Survey Results

	Importance in my professional life			How well the UM prepared me		
	72	82	87	72	82	87
design and creativity	3.8	4.1	4.2	3.2	3.2	2.9
engr. economics	3.3	3.1	3.3	2.4	2.5	2.5
technical communication	4.2	4.5	4.4	3.2	3.0	3.5
interpersonal skills	4.3	4.6	4.4	2.6	2.5	2.4
professional ethics	3.7	4.1	4.2	3.2	3.2	2.8
understanding social/ethical aspects of my work	3.6	3.4	3.7	2.9	2.7	2.3
math and physics	3.4	3.6	3.8	3.8	4.0	4.0
dynamics	2.9	2.8	2.7	3.4	3.8	3.6
thermodynamics	2.7	2.6	2.3	3.5	3.9	3.6
solid mechanics	2.8	3.0	3.3	3.1	3.6	3.8
fluid dynamics	2.3	2.4	2.3	3.2	3.5	3.4
materials	3.2	3.3	3.5	3.1	3.5	3.7
heat transfer	2.7	2.8	2.3	3.5	3.6	3.4

Importance	How well prepared
1: never used/needed	1: no preparation
2: rarely useful	2: slight preparation
3: useful	3: some preparation
4: often useful	4: good preparation
5: always useful	5: excellent preparation

Table 2. Alumni were asked to indicate the relative importance along with their level of preparation in a variety of areas. A sampling of the questions and answers are shown.

A different questionnaire, distributed to MEAM seniors, was designed to provide answers to the following questions:

- How well did the program satisfy the students' expectations?
- Why would a student's career at Michigan take longer than four years?
- Which courses were the most informative/enjoyable? Why?
- Which courses were the least informative/enjoyable? Why?
- What are the students' future plans?

This questionnaire was distributed to the senior design class and at a meeting of Pi Tau Sigma (Honor Society) late in the Fall term of 1992. Approximately one hundred students responded, which is close to the number who graduated at the end of that term.

The majority of the seniors agreed with the alumni about the lack of preparation in communications, design, real-world problem solving, and engineering economy. Most said they would like more electives, and many expressed an interest in joint degrees, perhaps reflecting the role of mechanical engineering as a "default" choice for some students or the choice with the best job prospects. An overwhelming majority expressed an interest in combined Bachelor and Masters degree.

The students generally expected to take more than eight terms to complete their Bachelor degrees and indicated that the announced "standard" load of 16 credit was too heavy. Many required classes in the core curriculum are fewer than four credit hours. Consequently, students need to take five courses per semester in order to graduate in four years (without significant advanced placement credit). Nearly all the students said that they would prefer classes with four credit hours each which would result in fewer classes overall. When asked about their favorite courses, the design sequence stood out as the most popular one. Our students generally have high expectations for themselves with two-thirds planning to go on to graduate school. Finally, a substantial majority was satisfied with mechanical engineering as their major and would select it again if given the choice. The student survey was repeated the following year with nearly identical results.

The comments from the external advisory committee were more informal, consisting of verbal comments during the annual visit of the committee. In general, their suggestions were consistent with the results of the surveys.

Thus, discussion with students, alumni, and industry leaders revealed a strong need for instruction in interpersonal skills and technical communications, social and economic factors that affect work, design and creativity, and manufacturing. These needs were not being met within the existing engineering core curriculum. Indeed, these shortcomings of the MEAM curriculum are by no means unique. A recent survey conducted by the National Society of Professional Engineers identified a lack of preparation in communications as the main failing of current Bachelor level engineering education (3).

Recommendations

The MEAM Undergraduate Curriculum Review Committee concluded that the engineering science and design core of the program was quite strong. However, the program needed modifications to meet the current needs of our constituents (i.e., students, alumni, and industry). Changes should be devised which remedy the shortcomings described above while maintaining a strong engineering science core.

The required course sequence should be altered (with new courses, if necessary) to address two basic issues:

1. The background of the incoming students is changing rapidly. In the past, most of the incoming students had considerable hands on experience, and it could be assumed that students had some experience with basic tools and common machinery. Today, however, students generally have little or no exposure to mechanical devices. Instead,

students may have much more experience with computers. Experience with simple and complex engineering systems must come from modern instructional laboratories and the design course sequence.

2. Industry increasingly relies upon a team approach to problem solving, and the increasing mobility of the average engineer requires more emphasis on teamwork experience and communication skills. These skills must be emphasized in the curriculum.

While these two factors were the primary reasons for change, the committee felt there where a number of other drivers for change, some of which would be better addressed at the level of individual courses. Those included the following:

- The proliferation of new problem solving tools (such as engineering software packages) which permit more emphasis on design and optimization.

- Rapidly changing technology that necessitates introduction of new material into the core curriculum that may not have been traditionally considered "mechanical." Students should be given the opportunity to customize their undergraduate degree through both technical and free electives.

To incorporate these recommendations into the curriculum, the committee proposed a number of specific changes to the structure of the MEAM program. The main features of the new curriculum are the following:

- Restructuring of the required MEAM curriculum into five core sequences in Design and Manufacturing, Dynamics and Controls, Materials and Structures, Thermal/Fluid Sciences, and Instructional Laboratories.

- Introduction of a sophomore level course in the Design and Manufacturing sequence to complement the current junior and senior level design courses.

- Consolidation of all required laboratories into a junior and a senior laboratory sequence. These laboratories will emphasize teamwork skills and written and oral communication.

- Reorganize the core curriculum into four credit hour courses. Students would then enroll in four, four credit hour courses per semester (the "$4 \otimes 4 \otimes 8$ Model") for the majority of their progress through the core curriculum.

Following the review conducted by MEAM, other departments in the college conducted similar surveys. Moreover, in the Summer of 1995 a college level committee was appointed to evaluate the common required core required of all engineering undergraduates to ensure coherence between the various curriculum reforms in the College. The committee delivered its report to the faculty in April of 1996 and the faculty voted with a large majority to adopt its recommendations.

The result of this review is an action plan entitled "Michigan Curriculum 2000" (4) which includes many of the recommendations originally put forward by MEAM. The report details 21 specific recommendations which include

- Introduction of a Freshmen Engineering class.
- Restructuring of all departmental core sequences in the "$4 \otimes 4 \otimes 8$ Model".
- Integration of the required college level technical communications course into the core engineering curriculum of each department.

The main purpose of the $4 \otimes 4 \otimes 8$ Model is to make 16 credit hours the standard load for most students, resulting in graduation after eight terms (for students without significant advanced placement or transfer credits). In addition, students would take four courses per semester, allowing greater concentration on each subject. Course scheduling will be made easier, and the students would take the classes in the desired sequence. Enlarging courses from three to four credit hours may offer more opportunities for "open ended" problems and computing assignments. There are, however, some potential difficulties. Students may decide to take only three of the (now more involved) four credit courses a semester. More importantly, it may be difficult to cover a wide variety of topics in fewer core courses.

Implementation and Current Status

After considerable discussions, the MEAM faculty approved the recommendations of the review committee with the understanding that all specific changes would be brought to the faculty for separate discussion and vote. Implementation of the reforms has initially focused on the Design and Manufacturing and the Laboratory sequences. Two courses in design at the junior and senior level were already in place. A sophomore level course was introduced in the fall of 1994. In the sophomore course, the students are introduced to engineering design, various manufacturing processes, Computer Aided Design, and basic machining operations. Student teams work on a design project and produce a device prototype. The junior course is a more traditional mechanical component class, although a pilot version based on a more project oriented approach was offered in the Fall of 1995. The senior level course has been in its current form for several years. Two lectures per week introduce the students to various aspects of design but the remainder of the class time is devoted to project work. The students are divided into teams of 4 to 5 members who work on a single project (which in almost all cases is industry sponsored). The writing of reports and oral presentations during design reviews have been an integral part of the senior design class for several years.

Prior to 1990, all required laboratories had been associated with lecture classes. While some of these laboratories had been maintained and updated by interested faculty members, others had not, and in many cases the laboratories were run by teaching assistants with little guidance from the lecturing faculty. A year prior to the curriculum review, the laboratories in the thermal/fluid sciences had been consolidated in a single class. The laboratories of the material and mechanics course were later combined with those of the dynamics course to create a second laboratory class. These two classes represent an intermediate step toward the goal of a junior and senior level laboratory course sequence. The final step, converting the courses to a junior and a senior class will take place in the fall of 1997. The junior level laboratory will consist of single week laboratories and two-week midterm and final labs. The senior level laboratory will consist of four extended laboratories that emphasize analysis of relatively complex engineering systems. One of the senior laboratories will be student-designed. Formal instruction in technical communications will be incorporated into this new course sequence.

The implementation of the recommended changes in the engineering science courses was spurred on by the recommendation of the College Review Committee that the $4 \otimes 4 \otimes 8$ Model should become a College standard. During the Fall of 1996 the faculty discussed how the new model will affect the offerings in their core area and suggested how the curriculum changes should proceed. It is expected that modification of the core curriculum will begin in the Fall of 1997. The overall structure of the anticipated program is shown in Table 3.

While there is widespread support for the reforms among the faculty, a number of significant concerns have been voiced, especially regarding modification of the core curriculum. Practical issues involve the distribution of teaching load and how individual faculty will be supported the department as they manage significant modifications to the core courses. However, important pedagogical issues have been raised. Will larger core courses make it more difficult for the students to gain exposure to many different subjects? Ideally, the large format will allow more integration and demonstration of the interrelationship between the various topics. For electives, however, this can be a serious concern and at the moment there is no enthusiasm among the faculty to uniformly increase the size of all elective courses to four credit hours.

An often cited concern is that reorganization of the core curriculum will result in its diminishment. A small reduction in the number of required core credit hours may occur with these credit hours going over to technical electives. While the increase in elective credit will offer the student the opportunity to enrich their technical expertise, many students may not choose their electives wisely. One solution currently being discussed would ensure that the technical electives provide added depth in at least one area.

TERM	MATH	SCIENCE	HUMANITIES/ SOCIAL SCIENCES	ENGINEERING PRACTICE	ENGINEERING SCIENCE	FREE ELECTIVES
1	Math 1	Physics 1	Hum./Soc. Sci.	Comp. Science		
2	Math 2	Physics 2	Hum./Soc. Sci.	Intro. Eng.		
3	Math 3	Chemsitry		Design/Mfg. 1	Therm/Fluid 1	
4	Math 4		Hum./Soc. Sci.		Mat./Sol. Mech. 1 Dyn./Sys./Ctr. 1	
5	Math Elect.			Laboratory 1	Therm/Fluid 2 Mat./Sol. Mech. 1	
6			Hum./Soc. Sci.	Design/Mfg. 2 Electrical Eng.	Dyn./Sys./Ctr. 2	
7				Laboratory 2	Tech. Elect. Tech. Elect.	Free Elect.
8				Design/Mfg. 3	Tech. Elect.	Free Elect. Free Elect.

Table 3. A sample program employing the new $4 \otimes 4 \otimes 8$ curriculum.

Conclusions

The Department of Mechanical Engineering and Applied Mechanics at the University of Michigan is among the largest departments in the country, graduating a significant number of students with Bachelor Degrees in Mechanical Engineering every year (7,8). Our program has a long tradition of innovative undergraduate education in mechanical engineering, and our curriculum review initiated in 1992 represents the latest step in the evolution of our program. The needs of our program revealed by our review result from basic changes in the background of incoming freshmen and the rapidly changing requirements of our graduates over the course of their careers. These realities are faced by all undergraduate programs. As such, we hope that the successful implementation of our reforms will result in a new curriculum framework that faculty of other mechanical engineering programs may examine. We will continue to report on the progress of our curriculum reform.

References

(1) "Restructuring Engineering Education: A Focus on Change," National Science Foundation, NSF 95-65, 1995.

(2) 1993 Alumni Survey. Report available from the Department of Mechanical Engineering and Applied Mechanics, University of Michigan.

(3) "Report on Survey of Opinions by Engineering Deans and Employers of Engineering Graduates on the First Professional Degree", National Society of Professional Engineers, NSPE Publication No. 3059, 1992.

(4) "Michigan Curriculum 2000", Report available from the Dean of Undergraduate Studies, College of Engineering, University of Michigan.

(5) "Engineering Criteria 2000." Engineering Accreditation Commission and The Accreditation Board for Engineering and Technology (ABET).

(6) "Criteria for Accrediting Programs in Engineering in the United States." Accreditation Commission and The Accreditation Board for Engineering and Technology (ABET).

(7) In 1992 the Department ranked number 3 in number of Bachelor's Degrees awarded according to the Engineering Manpower Commission (202 296-2237)

(8) In 1995 the ME undergraduate program was ranked number three (along with six other institutions) by *U.S. News & World Report*

Author Biographies

Dawn Tilbury received her Ph.D. in Electrical Engineering and Computer Sciences at the University of California, Berkeley in 1994, and has been an Assistant Professor at the University of Michigan since January of 1995. Her research interests are in the area of nonlinear control with applications to robotics and manufacturing.

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