2006-698: A NEW MODEL FOR UNDERGRADUATE ENGINEERING EDUCATION? THE ENGINEERING MANAGEMENT CURRICULUM AT THE UNIVERSITY OF ARIZONA: A TEMPLATE FOR UNDERGRADUATE ENGINEERING EDUCATION

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The Engineering Management Curriculum at the University of Arizona: A Template for Undergraduate Engineering Education

Introduction

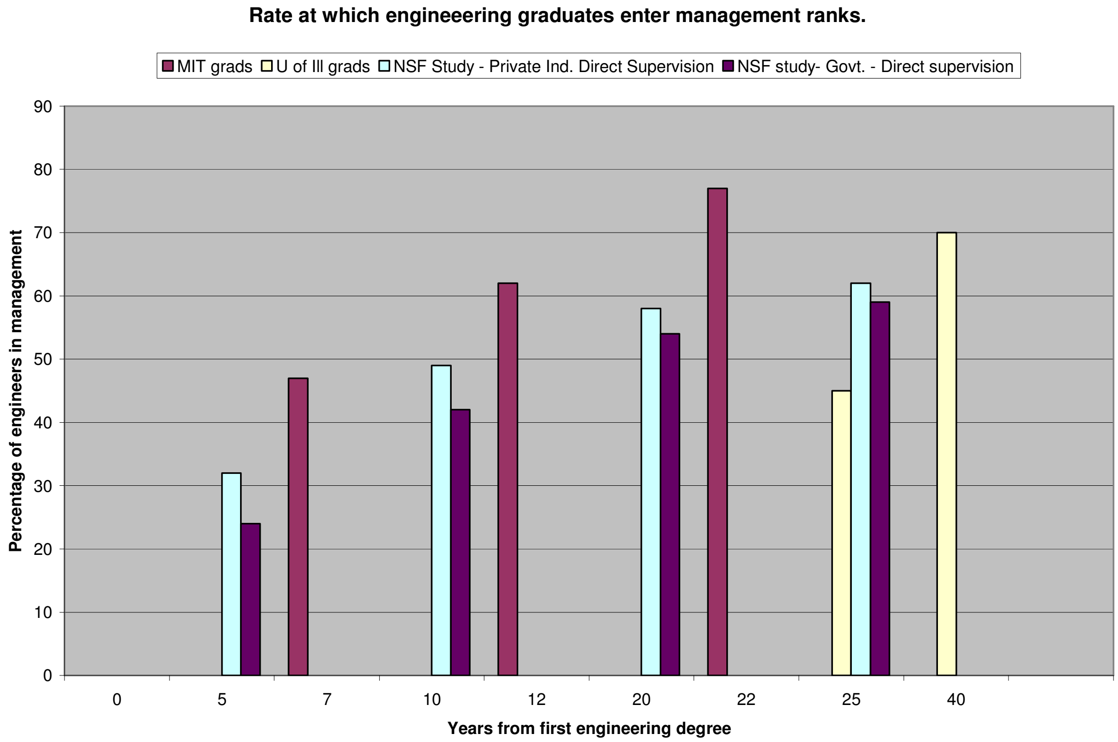
The role of the engineering graduate in society has been studied and it is clear that many holder's of a Bachelor's degree in engineering are not doing engineering, but instead are in the ranks of management, from shift supervisor, early in their career, to senior management at later career stages. For instance, in 1985 a major study was undertaken by the National Research Council [(1)] which found that 44.6% of those surveyed, who described themselves as engineers, said that their primary activities were management (28%) or production (16.6%).

In 1995, a similar survey by NSF[(2)] found that only 38% of those in the U.S. workforce with a B.S. in engineering actually work as engineers. An additional 48% say that their work is related to engineering, but that they are managers, patent attorneys, CEO's, financial analysts, and entrepreneurs.

In 1998, NSF published the results of its Engineering Workforce Project'[(3)] an ongoing effort. It showed that in 1993 32% of respondents said their primary work activity was management or production, but 49% mentioned management as a work activity, 42% mentioned accounting, 33% mentioned quality or productivity, 23% mentioned employee relations and 14% production.

A study of MIT graduates in 1992 [(4)] showed that 40% of the graduates in the Class of 1985 (seven years after graduation) had middle manager responsibility and 7% were senior managers or owners of companies. Those numbers increased to 49% and 13%, respectively, for the Class of 1980, and 37% and 40% for the Class of 1970. A 1998 study of University of Illinois College of Engineering graduates[(5)] showed that 45% of the Class of 1973 was in some management or supervisory capacity, and for all Classes, 70% were managers, officers or owners of businesses.

A 1995 study for NSF by R. Weatherall'[(6)] Table 1, showed again the rapid rate at which engineers go from their first degree into supervision or management. These data are shown in Figure 1. and Table 1.



The picture that emerges is clear: a large proportion of graduates with B.S. degrees in engineering do not actually practice engineering for long, with many of them entering the ranks of management within a relatively few years, if not immediately. Yet, the engineering education that most get is generally lacking in any component that educates them in how to deal with management issues. Industry is often looking to hire engineers for its supervisory and management ranks, primarily because the businesses they are in, such as manufacturing, utilities, and transportation, are technologically-based, and they need to have managers who understand enough about technology to learn and understand their specific businesses. While engineering graduates are the best suited for that, they do not have the education in business and management, particularly in communications and people skills, that are required, not to mention quality management, project management,, and legal aspects of management. While some go back to school to obtain these skills, at considerable expense in time and money, many do not, which hampers their promotion and effectiveness.

National Recommendations

In 1995, the Board on Engineering Education (BEEd) of the Commission on Engineering and Technical Systems of the National Research Council issued a report entitled Engineering Education: Designing an Adaptive System [7]. In that report, the BEEd described its vision of a new undergraduate engineering curriculum, which it said should:

1. “Provide broad, solid knowledge of key fundamental concepts in science and engineering. These concepts should not be taught only in the abstract but also with constant reference to engineering practice.
2. Provide in-depth engineering study in at least one field. Part of this study should address business and management aspects in that field…. and encompass a focus on global practice- some of which may be captured in a capstone design project.”

….

5. Provide greater flexibility to pursue other careers outside engineering.

Among other suggestions, the BEEd proposed integrating into the curriculum

1. “exposure to the concepts of business, economics, marketing and manufacturing and risk.
2. Sustainable development of the environment and
3. Engineering management, including effective interaction with shop-floor and technical support personnel.”

They also recommended “ remove some material and some courses from the current curriculum. …Remove redundancies, for example the repetitious teaching of the same principles of chemistry, physics and thermodynamics in different courses. Incorporate some math and science “base” courses into engineering courses. Emphasize in-depth one area of engineering practice in a discipline and provide a broad overview of other areas….Ensure that students in a given discipline have at least some familiarity with other engineering disciplines; multidisciplinary capstone design projects can help.”

And finally, the BEEd recommended going “ to a five year curriculum, with the first four years providing a broad Bachelor of Science degree and the fifth year leading to an in-depth professional specialization degree.”

More recently, a distinguished panel of the NAE[9] has written in <u>The Engineer of 2020,</u> “(engineering) students are still largely assigned to and educated in a single department, and as engineering disciplines have proliferated and clearly delineated specialties within these sub-disciplines have evolved, providing a broad engineering education to students has become an enormous challenge. ….. <u>Engineering education must avoid the cliché of teaching more and more about less and less, until it teaches everything about nothing</u>.” And, “ The comfortable notion that a person learns all that he or she needs to know in a four-year engineering program just is not true and never was. Not even the “fundamentals” are fixed, as new technologies enter the engineers toolkit.” The report goes on to extol the leadership role of engineers in the future in solving societal problems. Finally, it states that “ In the past, engineers who mastered the principles of business and management were rewarded with leadership roles. This will be no different in the future.”

Curriculum Development

In spring of 2000, based on observations after 20 years in industry as a senior officer in a number of industrial organizations, and also on recall of a very popular and successful undergraduate program at Yale, it was apparent that perhaps undergraduate engineering students were not getting a very useful education. (The Yale program in the School of Engineering was known as Industrial Administration. In fact 60 % of Yale engineering graduates, who typically constituted 20% of all undergraduates, were IA majors. Many went on to very successful careers in industry.) It was clear that something similar was needed today, and that it was time to implement the recommendations of the BEED.

An interdisciplinary committee was formed in the College of Engineering at the University of Arizona, utilizing the faculty with industrial experience who understood what was needed, and a proposal ultimately was put forward to the Arizona Board of Regents in May, 2000 to establish the B.S. Engineering Management Program . After two cycles through ABOR, in April, 2002 we received permission to offer the degree. It was based on the concept that it must be accreditable as an engineering program, it must provide a base level of knowledge in core engineering sciences, it must be flexible with regard to mathematics and science requirements as long as the total meets the ABET requirements. It must cover all of the elements of management that the graduate needs, and it must give flexibility, within limits, to the technical area of concentration that the student chooses.

The four-year, 128-credit, curriculum consists of several major course categories: Business/management-oriented courses, Engineering/technical courses, Humanities and Social Science courses, and Science and Mathematically-oriented courses.

In the first group of courses are 30 credits of required courses dealing with the Sociology of the Workplace, Corporate Communications skills, Financial Accounting, Operations Management tools, Quality Management, Project and Financial Management, Human resource Management, Technical Sales and Marketing, and Legal Issues faced by engineering managers. All but two of these courses are taught in the College of Engineering.

In the Science courses, basic Physics and Chemistry are required, with provision to substitute Biology for part of Chemistry, if desired.

In the Mathematics portion of the curriculum, fundamental differential and integral calculus is covered, as well as differential equations and a sound basis in probability and statistics. Depending on the technical area of concentration some students may take more mathematics, or they may take an advanced science instead.

Technical Areas of Concentration

Finally, in the Engineering/technical section, there is a requirement for a breadth of core course work in engineering sciences, including engineering mechanics, material and energy balances, electrical systems, and systems simulation. Any engineer going to work for a technologically-based industry needs to be conversant with these topics, even if he/she is not an expert. The trend is to hire outside experts to solve problems in many areas, but the manager must be able to converse with the experts and understand their recommendations. Beyond this core of courses, the student is free to elect an 18-credit total sequence of technical courses in an industrial or professional area of interest to him/her. This election is done with an advisor to ensure that it is a coherent sequence.

The 18 credits of technical electives that are a part of the Engineering Management curriculum can be used to obtain a formal minor in one of the other engineering fields or can be tailored to individual interests. Currently or recently, students in the program have pursued technical areas of concentration given in Table 2.

Table 2. Areas of Technical Concentration of Current JR and SR Single majors (85)

– ME Minor	16
– EE Minor	3
– ComputerE Minor	7
– CE Minor	3
– Construction mgmt	9
– Manufacturing	7
– Food Processing	4
– Mechanical	4
– Bioengineering.	2
– Process Engr.	2
– Environmental mgmt.	1
– All others @1	

Finally, all students must get an internship, or find a mentor, in some outside organization, company, or government agency during their senior summer/year, define a problem within their area of expertise that the organization wants solved, and solve the problem by the end of their senior year. For this they earn 5 Capstone Internship credits. They all give an oral and written presentation of the project and the results in order to graduate.

Fifth Year Leading to Masters Degrees

Some students may choose to take an additional year (30 credits) and earn a double degree in Engineering Management and another Engineering field. A student who wishes to do this may find that instead of two B.S. degrees, if their grade-point average is 3.0 or better in the last 60 credits earned, they may be eligible to apply to graduate school after they complete the B.S. Engineering Management degree and earn an M.S. in the engineering field they choose. Proper selection of the 18 credits of technical electives will usually qualify the student for M.S. study with no remedial course work required, and the M.S. degree typically requires the same 30 credits of additional work beyond the B.S. degree. **Either of these two routes satisfies the objective of the BEED to have the fifth year of study be the first professional degree.** Currently we have 18 students pursuing a double major, and 7 in the BS/MS track, across a broad spectrum of interest areas, Table 3.

Table 3 The fields in which students are taking a double major or following a BSEMG/MS Engr. Track

Double major		BS/MS track	
EE	4	CE	2
CE	4	EE	1
ChE	3	ME	2
MatSci	2	Min E	1
AeroE.	1		
ME	1		
Mining	1		
Optical E.	1		
BioSyst E.	1		

It is interesting to examine the courses taken by an EMG student electing to take a Minor in an engineering field. For example, a student taking a Minor in mechanical engineering will include in their course of studies: statics, solid mechanics, fluid mechanics, dynamics, thermodynamics, and a choice of machine design, heat transfer, controls, or engineering materials. Looking at the courses in ME that would be taken beyond those, in order to get a BSME degree, all of them are applications of these fundamentals, not new fundamentals. And most also carry senior/graduate credit. Thus the EMG graduate with the minor track is fully prepared to pursue an MS degree, the first professional degree, <u>if he/she wants to practice engineering</u>, or to go into industry fully prepared to undertake management-type duties without the need to go back to school, knowing the fundamentals of mechanical engineering and able to apply them to the specifics of a given business. Such a program was described for materials science students in 1991.[8]

The same analysis holds true for electrical engineering, civil engineering, materials engineering, etc. The 18 credits of junior-senior level coursework in each case covers most, if not all of the essentials of the field, with the additional senior-level coursework involving applications of the basics to various situations, usually of interest to the faculty, and rarely specific to the industry a student ends up in. Thus, in each case, the graduate at the end of four years has a good choice: either go into industry, pursue a management career <u>without the need to obtain an MBA</u>, or decide later whether to get the professional level courses via an MS, or decide now to pursue the MS. Many students tell us they like this flexibility.

Results to Date and Conclusions

By May of 2003, we had 91 students who had declared the major, and we had graduated 5, all but one of whom were double majors taking the degree as a fifth year. By May of 2004, the total majors had grown to 130 and we graduated 11 that year , and in May, 2005 we counted 182 majors, with 31 graduates in 2004-05. We have over 215 majors now and will have 40 graduates in 2005-2006. Students are distributed across all four years, with the largest group categorized as Juniors, since many students hit their first courses in ME, EE, etc. and decide they don't want to do that the rest of their lives. (This should not be surprising, since practically no freshman engineering student has any idea what an engineer does: their parents have told them that engineers make good salaries (which is not really true a few years out, unless they have gone into management!))

Because of the use of many existing courses throughout the College of Engineering, we are essentially a Virtual Program. Four part-time faculty teach the engineering economics and finance, project management, human resource management, planning, legal, and sales and marketing coursework, and do the advising. The latter is the key to the success of the program. We do no advertising except word-of-mouth, but we are willing to spend time talking to students about their careers.

Graduates appear to have no trouble obtaining jobs, many ending up with the firms with whom they conducted their senior internship. Many have multiple offers. The most commonly heard comment we hear from employers is “I wish this program had been available when I went to school!” The average annual salary for the 31 graduates in 2004-05 was $52,700 with a range from $44,000 to $62,000.

In the Fall of 2004, we underwent ABET accreditation review. In August, 2005 we were informed that we had been granted full accreditation until 2011, retroactive to 2003. This was a very welcome result, vindicating our belief that more flexible undergraduate engineering degrees are very desirable and that ABET is open to these kinds of programs, which we believe are the wave of the future. After all, they accomplish exactly what the National Research Council’s Board on Engineering Education said was needed.

References

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3. "U.S. Engineering Career Trends", L. Burton, L. Parker, and W. K. LeBold, Prism, May-June, 1998, ASEE.

4. Private communication, R. Weatherall, July, 2000.

5. Private communication, R. Weatherall, July, 2000.

6. Private communication, R. Weatherall, July, 2000.

7. Engineering Education: Designing an Adaptive System, National Academy Press, Washington, D.C. 1995.

8. “The Materials Curriculum in the 1990’s”, G. H. Geiger, J of Materials, May, 1991. TMS-AIME , Warrendale, PA.

9. The Engineer of 2020, National Academy of Engineering, National Academies Press, Washington, D.C. 2004.

Table 1. Management and supervisory activities of engineering graduates in private business and federal, state and local government, 1995 [2].

Year of first engineering degree		1991-94	1981-1990	1971-80	1961-70
Supervise the work of others directly					
	Private industry	32%	49%	58%	62%
	Government	24	42	54	59
Supervise the work of others through subordinates					
	Private industry	12%	20%	31%	38%
	Government	9	18	30	35
Managing and supervising are primary or secondary activity					
	Private industry	16%	30%	40%	43%
	Government	13	33	46	50

Appendix 1.

Student Academic Progress Form
Engineering Management Program

Required Course	Credits
ENGL 101*	3
ENGL 102 *	3
INDV 101	3
TRAD 101 (Non-Western)	3
INDV 103	3
TRAD 104	3
ART/Humanities Tier 2	3
Indv Tier 2 ECON 200*	3
CHEM 103a * General Chemistry I	3
CHEM 104a General Chem. Lab I	1
CHEM 103b * General Chem II	3
CHEM 104b General Chem Lab II	1
PHYS 141 * Mechanics	4
PHYS 241 * Electricity and Magnetism	4
MATH 125 Differential Calculus I *	5
MATH 129 Integral Calculus II *	3
SIE 270 or Math 254, Differential Equations *	3
SIE 305 Probability and Statistics	3
MATH/SCIENCE ELECT, Calc III or Adv Chem or Physics	4

ENGR 170 C Programming or CAD *	3
ENGR 102 Intro to Engr.	3
CE 214 Statics	3
ECE 207, Elements of Elect. Engr.	3
CHEE 201, Material and Energy Balances	3
SIE 431, Systems Simulation	3
E.M. Seminar, ENGR 495S	1
SIE 498 Senior Capstone Internship	5
SOC 326, Workplace Sociology	3
SIE 462, Operations Management	3
ACCT 200, Financial Accounting	3
SIE 265, Engr Economics/Proj Mgmt	3
SIE 467 ENGR Management II	3
CHEE/ENGR 454 Law for Engineers	3
MIS 465 Total Quality Management	3
COMM 312 Corporate Communications	3
SIE 415 Technical Sales and Marketing	3
Business Elective (Usually Intermediate Macroecon.)	3
TECH ELECTIVES (18)	
	3
	3
	3
	3
	3
	3
	128