Int. J. Engng Ed. Vol. 19, No. 2, pp. 252–259, 2003
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Educating Entry-level Engineers: Are Broad-based Business/Managerial Skills a Key to Sustaining the US Innovation-based Economy?*

JOHN V. FARR and DONALD N. MERINO
Department of Systems Engineering and Engineering Management, Charles V. Schaefer Jr. School of Engineering, Stevens Institute of Technology, Castle Point on Hudson, Hoboken, New Jersey 07030, USA. E-mail: jfarr@stevens-tech.edu

Fewer college-bound students are entering engineering in the United States than at any time in the last fifteen years. This can be attributed to relatively low entry-level salaries of traditional engineering, the perception that there is limited opportunity for significant long-term earning potential, and they are not being provided with the necessary business and entrepreneurial acumen. This paper presents a comparison of how our university is incorporating management and business topics throughout the curriculum with other leading engineering institutions to develop more entrepreneurial engineers. We also present study results justifying the focus of our efforts and some important lessons learned.

DECLINE IN ENGINEERING ENROLLMENTS

ACCORDING TO the Engineering Workforce Commission, the percent of students in the US receiving undergraduate engineering degrees dropped by 19.8% from 1986 to 1999. What makes this number even more disturbing is that the overall number of degrees awards during that same period has increased by more than 18% [1]. Figure 1 shows a comparison of the four largest categories of degrees granted in the US as of 1970 over the last 30 years (taken from [2]). Note that the ratio of business to engineering majors at the undergraduate level has increased from 2.7 to 1 to 3.7 to 1. In 1991 the number of psychology majors surpassed the number of undergraduate engineers in the US. In 1999, approximately 13,000 more psychology majors graduated with undergraduate degrees than engineers in the US.

According to the US government [3], the demand for engineers (exclusive of computer-related fields) for the period 1998–2008 is projected to grow between 10 and 20%. Combining this demand with the fact that many engineers leave the profession to assume managerial roles and other service sector jobs, as well as retirements, creates a strong employment outlook for the near term. The question many university administrators are asking throughout the US is why are enrollments continuing to drop, when a huge demand for engineers exists?

Reasons for the decline in engineering enrollments

There are many reasons for the declining enrollments when there are numerous perceived opportunities for engineers. Farr [4] shows how salaries of civil engineers have not grown significantly beyond inflation in the last 20 years. He also compares billing rates for management consultants and civil engineers that showed disparities of up to 3 to 1 between similar size and located companies. Lewis [5] describes the compensation for making partner with one of the Big Six accounting firms that are the leaders in management consulting in the US. The average salary of around $500,000 (US) (without bonuses) that is typical for those being promoted to partner within a management-consulting firm. Few engineering firm owners in the US approach this level of compensation. Most academicians will tell you that their better graduates are being employed by the management consulting and other service sector employers in lieu of traditional engineering firms because of the financial rewards. This is certainly true of the engineering management and technology-intensive programs at our university.

Another issue is that most engineering schools are not providing the skills that industry needs for entry-level positions in our international and technology driven economy. This further supports the perception that leaders of the 'brick and click' and 'dot.com' economies of the 21st century will come from the legal, marketing, and business ranks. For

* Accepted 15 July 2002.

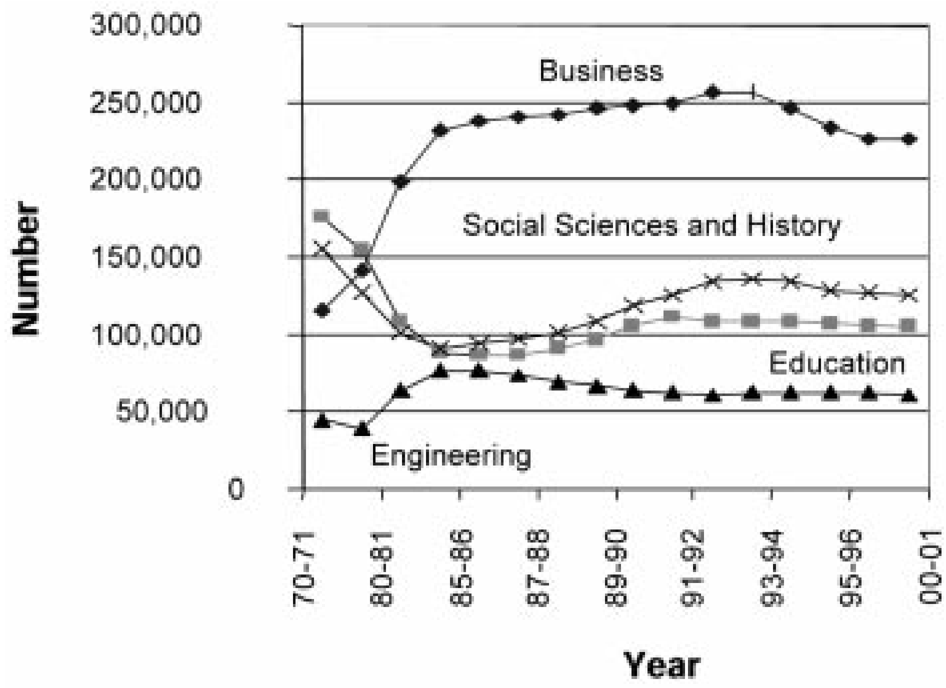

Fig. 1. Four largest categories of degrees awarded since 1970 [2].

engineering educators, broadening the curriculum to respond to these criticisms is old news and was the impetus behind changing the accreditation standards. Industry has long recognized the need for a 'different' type of engineer. The landmark 'Green Report' [6] published in 1994 stated that engineering education must be broadened to include:

- team skills, including collaborative, active learning;
- communication skills;
- leadership;
- a systems perspective;
- an understanding and appreciation of diversity;
- an appreciation of different cultures and business practices, and the understanding that the practice of engineering is now global;
- a multidisciplinary perspective;
- a commitment to quality, timeliness, and continuous improvement;
- an understanding of the societal, economic, and environmental impacts of engineering decisions;
- ethics.

That same ASEE report goes on to say 'Engineering schools should not seek to develop the contextual and process skills through separate courses, but by incorporating them into existing curricula and through non-classroom activities.' Most schools have adopted this philosophy. Most engineering faculty support this concept for introducing non-technical skills. However, this idea is difficult to implement in practice because most faculty members have little or no industry experience. Engineering faculty are hired, promoted, and rewarded based upon their technical and not their business knowledge.

SURVEY OF LEADING ENGINEERING PROGRAMS

Engineering programs have adopted numerous models for introducing non-math, science, and engineering concepts into their curriculum. We reviewed the curriculums of 10 leaders in engineering education in the US, according to *US News and World Report Magazine*. We chose 5 schools that are representative of the large research-focused universities. We also chose 5 schools whose primary mission is undergraduate education. Based upon information taken from the Web, Table 1 shows the total number of courses that are devoted to business/management topics and whether engineering economy is required.

Even though Engineering Economics is a required subject on the Fundamentals of Engineering (FE) and Professional Engineering (PE) licensure, only 7 out of 35 programs reviewed required this course. This finding indicates a bias toward technical topics since Engineering Economics is traditionally the only 'business' type courses in engineering curriculums. In general, engineering education has changed little in the US beyond the capstone experience. However, the change has been slow and in general has occurred by incorporating 'soft' topics espoused by industry into the design sequences. The overall conclusion is obvious: leading engineering programs schools do not contain sufficient subject matter to prepare engineers for the business aspects of their profession.

An analysis of the program curricula in Table 1 indicates that there were more ethics and professional practice courses than required business courses. All programs had a significant number

Table 1. Number of required management/business courses for 10 of the top engineering schools in the US

	Number of required business courses/ engineering economy course (Y or N)			
'Research universities'	Civil Engineering	Mechanical Engineering	Electrical Engineering	Chemical Engineering
Massachusetts Institute of Technology	0/N	0/N	0/N	0/N
Stanford University	1/Y	0/N	0/N	0/N
University of Michigan	0/N	0/N	0/N	0/N
Cornell University	0/Y	0/N	0/N	0/N
Georgia Institute of Technology	0/Y	0/Y	0/N	0/N
'Undergraduate teaching universities'				
United States Military Academy	0/N	0/N	0/N	No Program
Bucknell	0/Y[1]	0/N	0/N	0/N
Rose-Hulman Institute of Technology	0/Y	0/N	0/Y[2]	0/N
United States Air Force Academy	0/N[3]	No Program	0/N	No Program
United States Naval Academy	No Program	0/N	0/N	No Program

[1] Taught as part of a combined course with Project Management.
[2] Taught as part of a course on Engineering Practice.
[3] Engineering economy is taught as part of a course on Construction Management in one of the four stems in the program.

of humanities/social science courses. But few placed any limitations on their nature. Most had the opportunity to take Engineering Economy or other business or engineering practice type courses as a free elective. Note that in general there was not a difference in course content between what we deemed research and undergraduate teaching-focused universities.

The changing nature of engineering education

Engineering is changing. Many industries and societies outside the US have realized the contribution that engineers bring to technology-driven industries and services beyond technical expertise. Globalization and technology are having a profound effect on all sectors of an industrialized economy. We believe that within the last 10 years a paradigm shift is occurring in the US where engineering is becoming more focused on a greater breadth of knowledge. One example is the National Science's Foundation Bachelor of Arts in Engineering at the University of Arizona [7]. Our university requires a four-credit engineering economy and a two-hour credit business practices course focused on the economics of the student's senior design.

Young [8] reported that the Institute for Engineers in Australia mandated that 10% of the course content in undergraduate engineering curriculum be management. This was based on a survey that found working engineers spend 42% of their time on 'Management Supervision' as their dominant

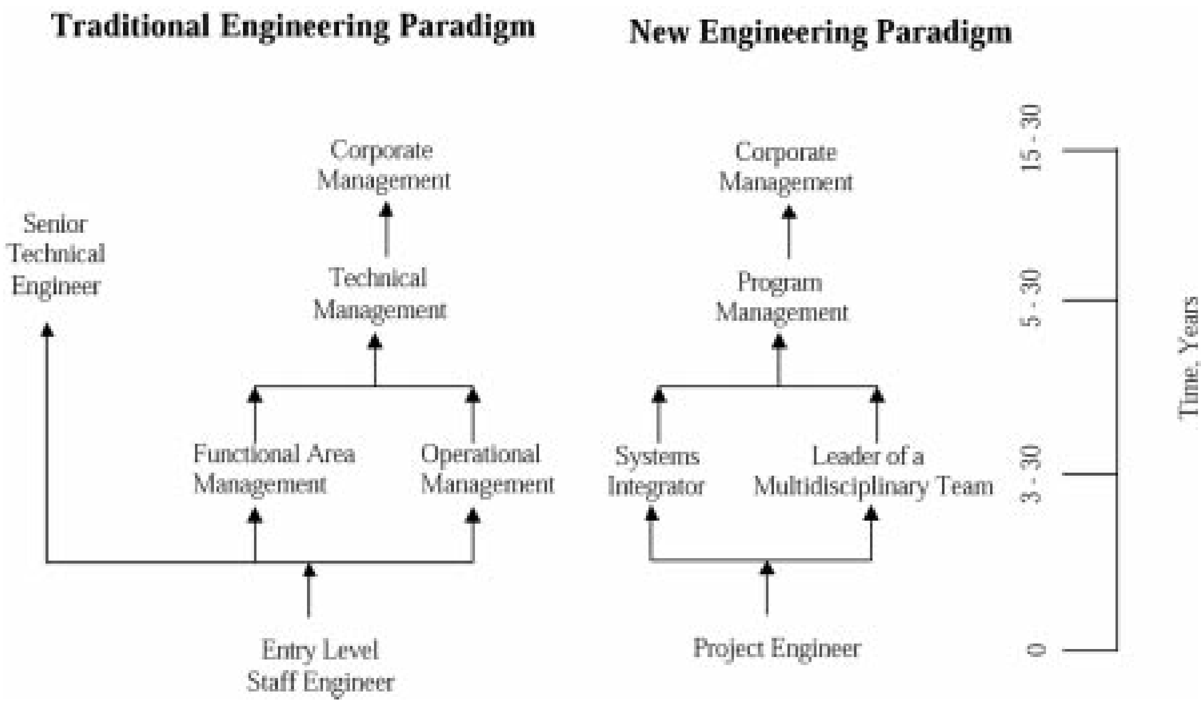

Fig. 2. Traditional versus new engineering paradigm.

function. The US Workforce commission survey supports this finding.

The changing role of the modern engineer in the 21st century economy

As shown in Fig. 2, the roles of the engineer are changing. They must embrace management, working in multidisciplinary teams, and understand the non-technical aspects of their profession typically their first day on their new job upon graduation.

Figure 2 is based on a survey on how major US hi-tech companies (AT&T, IBM, etc.) and government research labs practice engineering [9]. The result was that these companies and government research labs practiced Concurrent Engineering. Concurrent Engineering uses a systems-oriented, multi-disciplinary team approach to determine the most cost-effective designs from a lifecycle perspective. A related literature survey [10] confirmed that this was wide spread in the US.

Figure 3 presents the skills that the ideal new engineering graduates (for all disciplines) should possess upon entering the job market and to practice Concurrent Engineering. Most schools, mainly through the capstone design experience, are trying to incorporate many of these skills.

Pace of change in engineering education

Why has engineering education been slow to change? The answer is complex and is influenced by a number of interrelated factors. Some of these include:

- External factors, which include the rapid change of both technology and business, that create shorter shelf lives for faculty knowledge.
- Institutional factors such as faculty governance that delegates responsibility for revising and integrating engineering curriculums to the discipline-specific faculty.

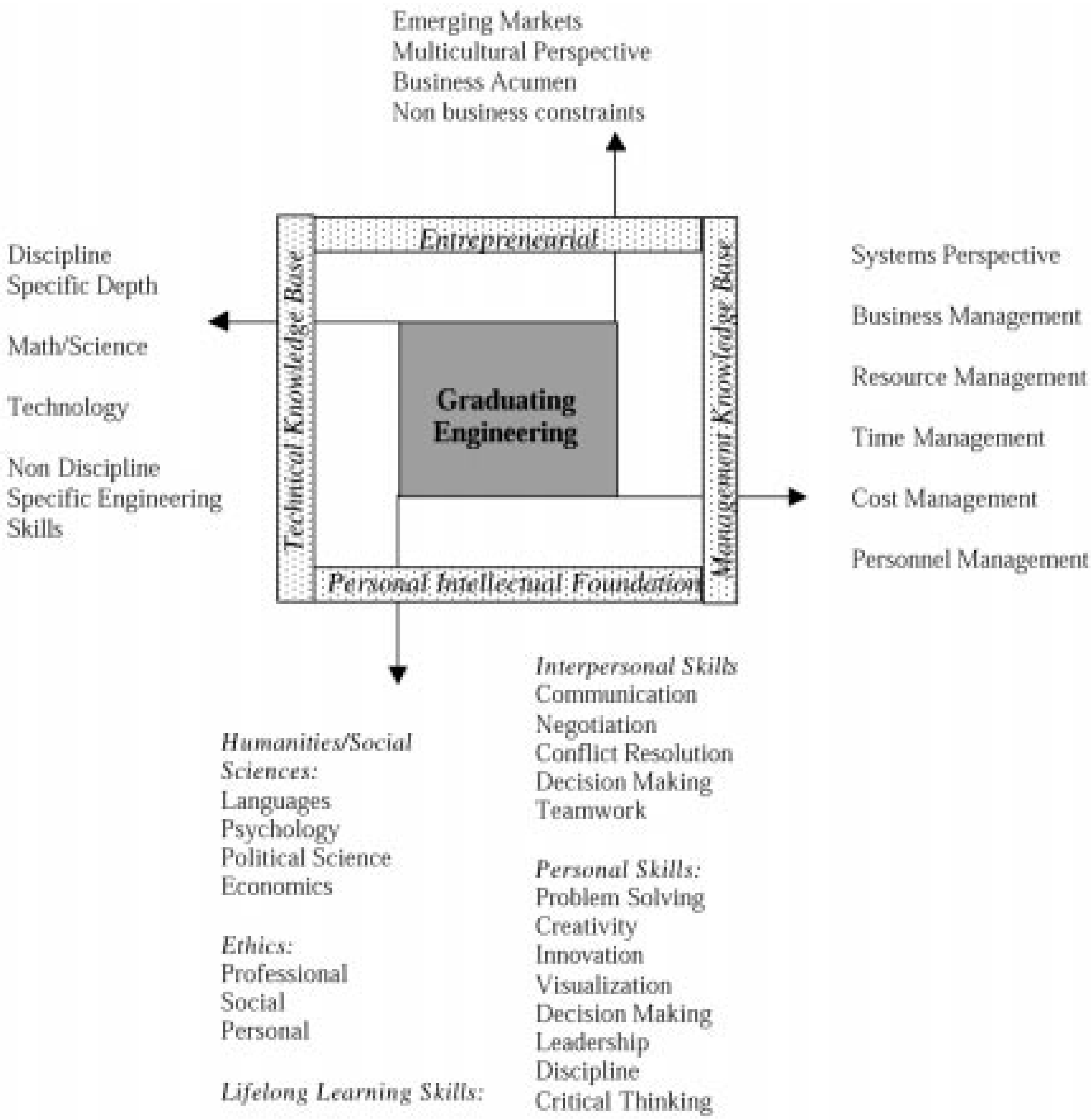

Fig. 3. Skills needed by the ideal graduating engineering student (modified from [11]).

- Institutional factors that include how faculty are recruited and evaluated for promotion and tenure.

These factors combine to create the following scenarios familiar to most engineering faculty:

- Curriculum revisions are driven by the need to increase both technical and business-related topics. However, in most cases, discipline-specific faculty is more concerned with changes in their technical specialty than in business topics. Given the limitation on total credits, it becomes very difficult to justify adding any additional credits for business topics at the perceived expense of technical topics. This is made even worse by the trend in some states to decrease credits because of cost concerns.
- Engineering professors are products of their environment. They model their programs after the major research institutions from which they graduated. Even the smaller undergraduate engineering education-focused universities recruit young engineers from the top research institutions. In addition, most engineering faculty lack extensive industrial experience which limits their knowledge and ability to incorporate business topics.
- Given that the reward system for engineering faculty promotion and tenure is heavily weighted towards technical contributions (funded research, refereed papers, etc.) then it is no wonder that changing curricula to increase broad-based business topics in practice is so difficult.

Accreditation changes (ABET 2000) in the US were formulated on a continuous improvement model where faculty needs to 'listen to the voice of the customer' to establish outcomes that engineers should achieve. While this was a major change in approach its success depends upon how comprehensive the engineering faculty surveys and listens to the 'customer' and then implements the changes. Even with this change there is still confusion about who 'is' the customer:

- Is the customer industry employers or is it national rankings (e.g. *US News and World Report*) that are heavily research/technical weighted?
- Is it traditional industries like manufacturing or engineering design.
- Is it non-traditional industries such as consulting, financial and dot.com entrepreneurial ventures?
- Is it traditional engineering disciplines that practices engineering in a sequential and single disciplinary way or concurrent engineering with its stress on multi-disciplinary approach?

WHAT KEY BUSINESS/MANAGERIAL SKILLS ARE NEEDED?

Numerous articles have been published in the literature that, based upon survey results, quantify what skills are needed for young project engineers. Odusami [12] presents a summary of nine papers that list these skills. Typically these papers attempt to quantify skills needed for project management type positions. The fourteen management skills that are most often referred to include (in roughly descending order of importance) are:

1. Communication,
2. Decision making,
3. Leadership and motivation,
4. Problem solving,
5. Planning and goal setting,
6. Organizing,
7. Listening,
8. Quality management,
9. Result orientation,
10. Financial management,
11. Time management,
12. Technical knowledge,
13. Delegating, and
14. Negotiation skills.

Numerous detailed studies exist within these 14 skills. For example, the skills presented in Fig. 4 by Merino [13] quantified the financial management skills needed by engineers.

More so than the specific 14 skills listed, we need to develop engineers with entrepreneurial and

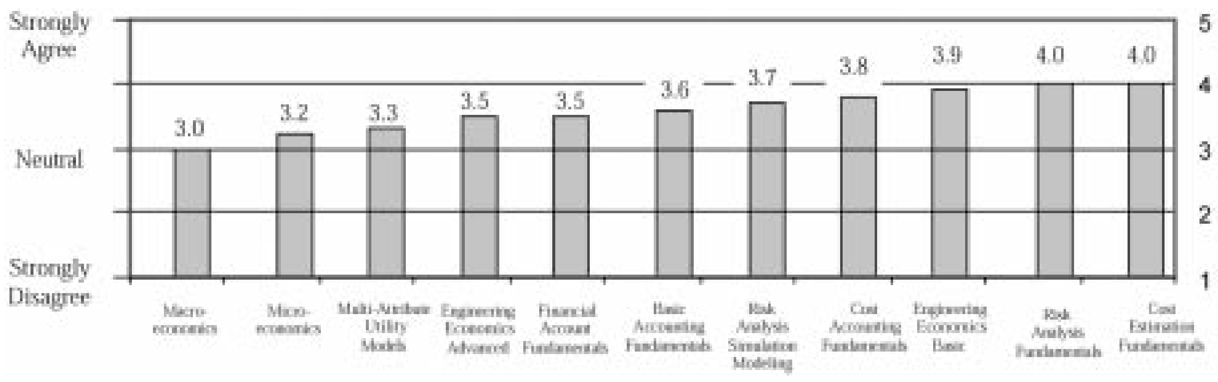

Fig. 4. Economic literacy's needed by engineers.

management aptitudes. Entrepreneurship is not a skill set, but a philosophical approach to engineering.

Merino [13] surveyed graduate engineers who supervised and hired entry-level engineers. While the sample represented a broad range of hi- tech companies in northern New Jersey, most of these companies are global in scope. The purpose of the survey was to determine what economic topics were important for entry-level engineers. Two conclusions support the needs for expending related topics. The first conclusion was that none of the topics were clearly eliminated. The second conclusion was that cost estimation/accounting and engineering economics were important topics, yet are not widely taught in top engineering school's traditional programs (see Table 1). Also note that risk analysis was very important for entry-level engineers and is also generally not taught to undergraduate engineers.

A SOLUTION TO SOLVE THE PROBLEM OF PROVIDING BUSINESS TOPICS TO THE ENGINEERS

Because of our locality, the employers of our students, and Stevens' rich history in business engineering (a Department of Business Engineering was established in 1902), we have made a significant commitment in terms of credit hours to developing engineering for an innovation-based economy. At Stevens we have chosen the model of integrating a group of business competencies into our traditional design sequences. Figure 5 shows the concept. This has been the major approach taken by other universities. Like most universities, we have obtained varying degrees of success mainly because the professors teaching the classes lack the skills necessary to integrate the various skills needed and the commitment to its importance at the undergraduate level.

In addition to the design spline, all engineering students are required to take a course in engineering economy with a lab. This course not only contains the traditional time value of money topics, but has web-based accounting modules, communications, and project management as part of the weekly laboratory. Lastly, under the auspices of the dean, we have developed a course titled Entrepreneurship and Business for Engineers and Scientists. This course will be an elective for seniors and graduate students in engineering and will be required for the engineering management schools. This combination of business and economic analysis courses provide our students with a wide variety of business tools.

In addition to engineering economy, all engineering disciplines are required to take another course titled Engineering Economic Design. We believe that this will be the major vehicle for instilling a business and entrepreneurial attitude. This course requires that the students develop economic models for their senior design project. This could take many forms to include a business plan, simple costs to manufacture, return on investment, etc. We have developed a web page with numerous discipline-specific case studies and an economic analysis spreadsheet tool. Fortunately, many of our faculty in our engineering

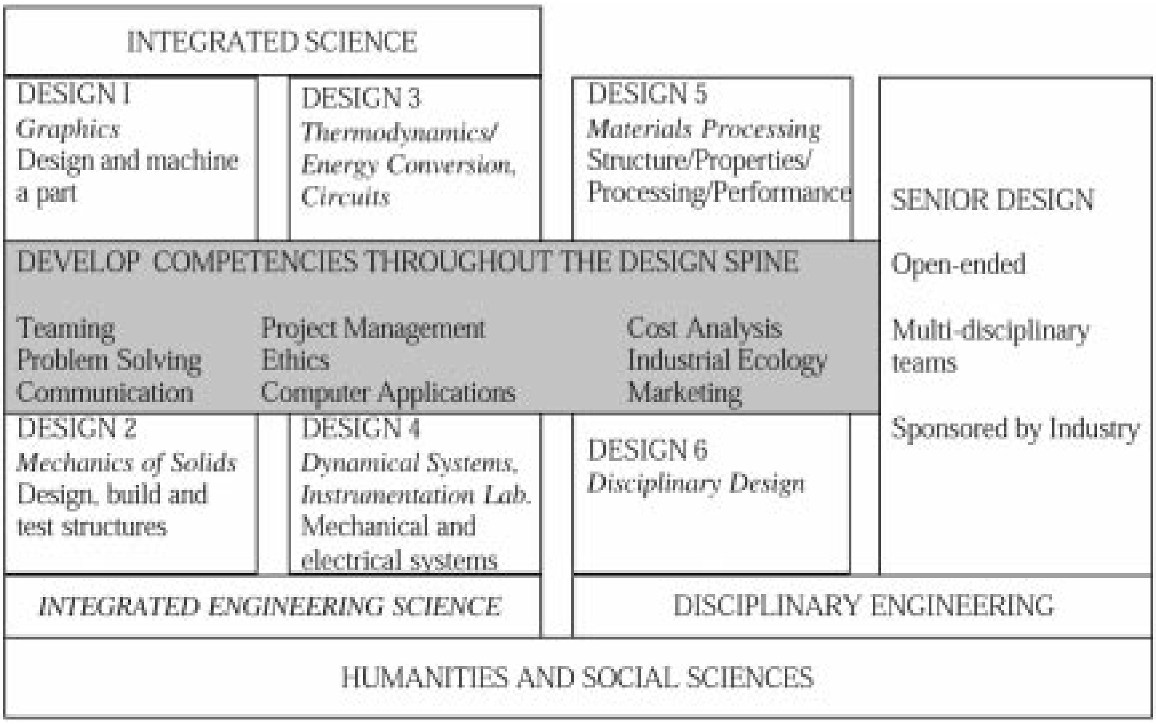

Fig. 5. The Stevens design spline.

management program has backgrounds in traditional engineering. They, not the faculty in the traditional departments, are responsible for assigning grades in this course.

With 150 semester credit hours needed for graduation, we have the luxury of requiring these courses. With input from a strong external board of advisors, program directors must make tradeoffs in technical, humanities, engineering practice, and management content. Our university has combined or eliminated many traditional technical courses to allow for business type courses. We also counsel our students to take advantage of their humanities options and take relevant business content courses such as macro and microeconomics.

CONCLUSIONS

There is a decline in engineering enrollments—particularly in the more traditional disciplines. Reasons for this decline vary from lack of financial rewards in traditional disciplines to the lack of business skills for those interested in more entrepreneurial-type jobs and industries. A survey of the top engineering schools' (both research and undergraduate education focused) traditional disciplines (the big four of Civil, Mechanical, Electrical and Chemical Engineering) indicates a lack of any business-orientated courses at the traditional research universities.

We observe that engineering and the role of engineers is changing. A number of studies indicate that the new engineering paradigm places even more emphasis on the business aspects of engineering. Yet we see very little change in engineering education to reflect the changing needs.

The Stevens experience is presented as a model to cope with the changes identified. However, the Stevens experience is influenced by our history (first Department of Business Engineering was founded in 1902) and an undergraduate curriculum with 150 semester credits—one of the largest in the US that allows both technical and business breadth. We are unlike most universities in that we have had to make technical tradeoffs.

Lessons learned

Listen to the voice of the customer. Overcome traditional disciplinary barriers and recognize engineering for what it is—a multi-disciplinary approach with heavy emphasis on economic and entrepreneurial and business skills. The customer will relay to you that they need graduates who can perform many simultaneous skills within a culture that rewards business and entrepreneurial skills.

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Donald Merino is a tenured full professor of Engineering Management and Management at Stevens Institute of Technology. He has developed undergraduate and graduate courses and teaches Engineering Economics, Decision Analysis, Total Quality Management, Strategic Business Planning and Concurrent Engineering. He is the founder and Program Director of the Executive Master in Technology Management (EMTM) Program. He was founder of the undergraduate Bachelor of Engineering in Engineering Management (BEEM) at Stevens. He won the Morton Distinguished Teaching Award for full professors at Stevens. He was PI to develop a concurrent engineering graduate program. John Wiley

published his book, 'The Selection Process for Capital Projects', in their Engineering and Technology Management series. Dr. Merino received two Centennial certificates from the ASEE in Engineering Economics and Engineering Management. He is past chair of the Engineering management Division and Engineering Economy Division of ASEE. Dr. Merino was awarded the B. Sarchet Award from the American Society of Engineering Management (ASEM) and the Engineering Management Division of the American Society of Engineering Education (ASEE). He is a Fellow and past president of ASEM. Dr. Merino has 25 years of industrial experience in positions of increasing managerial responsibilities. Since joining academe 18 years ago, he has published 24 refereed journal articles and conference papers and over 50 research reports in Design for Cost/Concurrent Engineering, Environmental Economics and Medical device development/Economics.

John V. Farr is a Professor of Systems Engineering and Engineering Management at Stevens Institute of Technology. He has authored or co-authored one book and over seventy technical publications in wide variety of fields including military engineering, modeling and simulation, engineering and technology management, and infrastructure assessment and management. After 10 years in industry, Dr. Farr joined the faculty at the U.S. Military Academy in 1992 as an Assistant Professor of Engineering Management and was promoted to Professor in 2000. He was responsible for the Academy's nationally recognized Engineering Management Program from 1997 to 2000. He is a Fellow and currently the Editor of the Journal of Management in Engineering of the American Society of Civil Engineers (ASCE) and the President Elect of the American Society of Engineering Management. He joined the faculty of Stevens in 2000 as the Founding Director of the Department of Systems Engineering and Engineering Management.