An Action Agenda for Engineering Curriculum Innovation[a]

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ABSTRACT

The signals for changes in engineering education that the deans of engineering receive are coming at a dizzying pace. These signals seem to come from everywhere and they are not always consistent. It is good that our colleges of engineering are conservative and don't change on a whim. But the evidence mounts that we need more innovation in our engineering education programs with better integration of subjects.

This paper provides an assessment of background studies on engineering education, and summarizes the progress in reform and improvement that are being made. Some key challenges for engineering educators within the universities are discussed. Finally, some predictions on the major changes that must occur in engineering education are mentioned.

Introduction. I shall briefly mention changes which are occurring in engineering practice and then, after providing a brief historical perspective, address how these changes will in turn create needed changes in engineering education. This fits in with the theme of this session, "Educational Institutions Respond to Changing Engineering Careers." Perhaps there is no single factor of greater importance in its effect on engineering education than the internationalization of engineering practice. International cooperation in engineering has reached unprecedented levels and continues to accelerate. Information technology and telecommunications make neighbors of the world's citizens. Communication among all is now possible is seconds. This could not be more dramatically illustrated than the incident a few months ago in which the malicious "I Love You" computer virus affected more than 294,000 host computers throughout the world and perhaps millions of individual PC's within hours.[1] Communication is at the speed of light.

Changes in Engineering Practice. In this section I will list several changes in engineering practice that are occurring. Undoubtedly there are more, but mentioning these will serve the purpose of my remarks.

1. New technologies emerge at a quickened pace
2. Companies narrow their focus to the core business
3. Design activity involves a broader range of disciplines
4. Globalization of engineering practice and increased competition
5. *Concept-to-product* time shortened
6. Design for the environment
7. Information technology
8. Engineers frequently change jobs more and companies also change more quickly
9. More engineers are working in small companies
10. Knowledge management is a greater factor in engineering practice

Changes in Engineering Education. To help understand today's national engineering education developments, one should look at the recent history of approaches by engineering educators. Up to and immediately after World War II engineering education in the U.S. was applications oriented and depended on standard handbooks. Laboratory courses provided hands-on experiences. Innovation and change was very slow.

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During the period 1960-1985, the computer entered the picture in a big way. Research money flowed and graduate studies boomed. There was virtually no external pressure on the universities to re-evaluate the engineering education being provided.

The period from 1985 to 1999 saw quickening globalization of industry and the multi-national global economy gained momentum – and worldwide competition caught the attention of industry leaders. Facing intense international competition in high quality products, corporations took advantage of the computational power readily available (CAD/CAM) and used fewer engineers to do a given job. Corporate leaders realized that more focus on quality was essential.

A Decade of Engineering Education Studies. Up until the last decade the periodic studies of engineering education have been infrequent, perhaps once every ten years. But since the late 1980s there has been a rash of studies indicating an increased level of concern about the education of engineers. John Prados[2] and Ed Ernst[3] both have provided excellent summaries of these past studies.

In 1989 the National Science Foundation empanelled a group of national experts in engineering to make recommendations regarding undergraduate engineering education. The summary of this seminal report,[4] which led to the establishment of the NSF engineering education coalitions, reads as follows:

> "The task force advocates, as a national imperative, a much strengthened undergraduate engineering initiative by the NSF in supporting the development of consortia of educational institutions as a complement to current engineering undergraduate curriculum activities and in this way to enhance the quality of undergraduate educational experience in engineering. The balance in many leading U.S. engineering schools between the teaching and research activities of faculty members can thus be restored, and the U.S. technological workforce's capability can be greatly enhanced. In this increasingly technological era more investment in the capability of the Nation's human resources in engineering is overdue."

The American Society for Engineering Education (ASEE), working with its Corporate Roundtable and Engineering Deans Council, also analyzed the change needed in engineering education and in 1994 published, 'Engineering Education for a Changing World".[5] The report said that engineering programs must be *relevant, attractive and connected*. Eight action items were specified for better education in the professional skills necessary for success in engineering. These include skills such as: 1) teaming (including active, collaborative learning); 2) communication; 3) leadership; 4) a systems perspective; 5) an appreciation of the diversity of students, faculty, and staff; 6) knowledge of different cultures and business practices; 7) understanding that engineering is now global; 8) respect for societal, economic and environmental impacts of engineering; 9) ethics; and 10) a deep appreciation for career-long learning.

After holding regional symposia throughout the U.S., the Board on Engineering Education (BEEd) of the National Research Council in 1995published its report, "Engineering Education: Designing an Adaptive System".[6] Again reform in the undergraduate education curriculum emerged as a very high priority item. During the 1990's most, but not all, of the studies on engineering education were focused on undergraduate education. The Committee on Science, Engineering and Public Policy of the National Academy of Engineering focused on the graduate education issue. Its comprehensive 207-page report lamented the excessive specialization within graduate programs. It stated, "What is needed is not additional specialization. We need a graduate system that is well tuned to the central feature of contemporary life: continuous change."

Two recent reports focus on undergraduate education in science, mathematics, engineering and technology (SME&T). The first is entitled, "From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering and Technology," and was published in 1996 by the National Academy Press.[7] Science and technical literacy among all students is the issue of major concern in this report. The belief is that in this global economy the nation will depend increasingly on a citizenry with a solid base of scientific and technical understanding. "Shaping the Future: New Expectations for

Undergraduate Education in Science, Mathematics, Engineering, and Technology' is a 1996 report of the NSF.[8] This comprehensive 76-page report concluded, "We can no longer be satisfied with incremental improvement in a highly commercialized competitive world of exponential change."

Finally, I mention the report that may well have more impact on U.S. engineering education than all of the others, i.e., the revised engineering accreditation criteria from the Engineering Accreditation Commission (EAC) of ABET.[9] The new accreditation criteria "Engineering Criteria 2000," are more flexible and require that each program have stated goals and a strong assessment program in place to measure output, i.e., the quality of the engineering graduates. Engineering Criteria 2000 comprises only three pages, although the individual professional societies will provide additional specific criteria for each engineering discipline. Criterion 3, on programs outcomes and assessment, states that in addition to the normal engineering and technical competence expected, graduates must demonstrate the ability to: 1) function on multi-disciplinary teams; 2) identify, formulate, and solve engineering problems; 3) understand professional and ethical responsibility; 4) communicate effectively; 5) understand the impact of engineering solutions in a global and societal context; 6) recognize the need for career-long learning; and, 7) show in-depth knowledge of contemporary issues and understand how they affect the practice of engineering.

Implications of Surveys of Practicing Engineers. Much on the engineering education challenges of globalization can be learned from engineers in industry. Engineers in multinational corporations are knowledgeable of the global dimensions of engineering work in their companies. I will briefly review four relevant surveys. The first is focused on undergraduate engineering education. The second and third address continuing education needs of graduate engineers. The fourth is a citizen survey on their expectations of universities.

1. A comprehensive undergraduate engineering education survey to gain data on technical and professional attributes of engineering graduates at the University of Illinois was conducted by the Dean's Student Advisory Committee.[10] It was sent to over 1700 alumni, faculty, industry engineers and students, with over 20 percent of the surveys returned. Ten attributes related to engineering practice were selected and the respondents were asked to first classify each in terms of importance and, second, judge each on the level of preparedness of engineering graduates. The results of all four groups that returned the survey are averaged in Table 1. It gives a comparison of importance of the attribute and preparedness of the graduates in each with the first item listed having the highest rank.

Table 1
The Relation Between Importance and Preparedness Rankings

Importance	Preparedness
1. Ability to identify and solve problems	1. Breadth and depth of technical background
2. Effectiveness in communicating ideas	2. Ability to use computers
3. High professional and ethical standards	3. Fundamental understanding of math and science
4. Inquisitive mind and positive attitude toward life	4. Ability to identify and solve problems
5. Breadth and depth of technical background	5. Motivation and capability for lifelong learning
6. Motivation and capability for lifelong learning	6. Inquisitive mind and positive attitude toward life
7. Ability to use computers	7. High professional and ethical standards
8. Fundamental understanding of math and science	8. Effectiveness in communicating ideas
9. Knowledge of business management practices	9. Understanding of world affairs and culture
10. Understanding of world affairs and culture	10. Knowledge of business management practices

Two noteworthy observations can be made from these results. The top three attributes in terms of importance are identifying and solving problems, communication skills, and professional/ethical standards. These rank 4th, 8th and 7th, respectively, in terms of perceived graduate preparedness. The top three attributes in terms of preparedness are technical skills, computers, and math and science understanding. These rank 5th, 7th, and 8th, respectively, in terms of importance. The many recent studies in engineering education indicate that *all* of these attributes are important. Above all, one should not be led to the conclusion that a strong technical background is not important. Instead, survey respondents are indicating relative satisfaction of the preparedness level of each attribute compared to others. No one suggests that the technical side of engineering education be weakened.

2. In 1997 the Joint Arizona Consortium – Manufacturing and Engineering Education for Tomorrow (JACME^{2}T) surveyed over 2500 working engineers from six high tech companies in Arizona.[11] The companies are Allied Signal, Raytheon, IBM, Intel, Boeing and Motorola. Over 1100 engineers completed and returned the survey – a very high return rate. JACME^{2}T is a consortium of Arizona universities (ASU, U of A, and NAU) and the six large manufacturing companies. Post-graduate, continuing education courses (both credit and non-credit) have been offered to engineers in these companies. The survey was to determine the size of the continuing education market and what factors are most important in a relative sense.

The overall results show that continuing education/training was considered to be very important to the future of the engineer with a score of 5.06 on a scale of 1 to 6 (with 1 being *not important* and 6 being *very important*). Consistently, the younger the engineer, the more important continuing education was. Those 25 or younger scored it 5.41 and those over 55 scored it 4.51. Also the more education one has, the higher the importance of continuing education/training.

Noteworthy, from the point of view of distance education analyses, the method of delivery – whether or not the course was offered remotely – is relatively unimportant. On the question of reasons for taking a course, eight options plus “other” were provided and the respondents were asked to check all that apply. The results are shown in Table 2. Note that to earn an advanced degree was the lowest ranking reason for taking a course for these fully employed engineers. Another question on the survey was, “How important are the following factors when deciding to enroll in a course?” Nine factors were listed and the respondents were asked to score them from 1 (not important) to 6 (very important). Table 3 provides survey results with the most important being at the top

The message here is that full-time engineering employees in industry are more interested in updating their skills to improve their potential for advancement in their current jobs as opposed to obtaining another degree or certificate. And method of delivery was near the bottom in importance These outcomes surprise most faculty who think of degrees as the *coin of the realm* in higher education. But the success of engineers in industry results from their knowledge and skills in solving industry problems, not more degrees.

Table 2
Reasons Why Fully-Employed High-Tech Engineers Take Courses

Reasons for taking a course	Percent checking item as applicable
To expand my knowledge base	84.58%
To perform better at my current position	83.03%
To be better qualified for promotion	70.46%
For a pay raise	60.55%
To prepare in case of downsizing	55.99%
To meet a company requirement	51.59%
To gain insights into another industry	48.32%
To get a degree	48.15%
Other	5.43%

Table 3
Ratings of Importance of Course Attributes

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Factor/Attribute of the course	Rating
Cost – Whether the company pays for the class	4.75
Relevancy – Whether or not I can use the course material immediately on the job	4.42
Flexible Schedule – Whether or not the courses are offered on nights or weekends	4.17
On Location –Whether or not the course is presented at my company's facilities	3.93
Approval – Whether or not the course is approved by my company	3.88
Frequency – Whether or not the course is offered several times during the year	3.59
Delivery – Whether or not the course is offered remotely, i.e., satellite	3.37
Credit – Whether or not the course counts towards a degree	3.00
Certificate – Whether or not the course contributes to a certificate	2.56

It is worthwhile to quickly look at these data in two other ways: 1) whether different views are held by engineers of different ages; and 2) whether the level of education of the respondents affected their answers. The results in Table 4 are very consistent, first by age and then by education level. BS+ indicates some graduate credit, but no graduate degree. It is noteworthy when one carefully reviews these data that the rank order of these factors is identical for all age levels and education levels with few minor exceptions which are shown in bold.

Table 4
Ratings of Course Characteristics by Age and Education Level

Factor	Age	<36	36-45	>45	Education level	<BS	BS	BS +	Masters
Cost		4.87	4.76	4.62		4.76	4.60	4.79	4.85
Relevancy		4.23	4.40	4.62		4.46	4.36	4.41	4.46
Flexible schedule		4.22	4.24	4.03		4.10	4.21	4.20	4.15
On location		**3.73**	4.08	3.91		3.83	**3.77**	4.06	4.06
Approval		**4.02**	3.83	3.82		3.79	**3.88**	3.87	3.91
Frequency		3.55	3.62	3.59		3.58	3.67	3.59	3.52
Delivery		**3.41**	3.51	3.16		3.16	3.45	3.51	3.32
Credit		**3.43**	3.11	**2.46**		3.12	3.18	3.10	2.70
Certificate		2.65	2.52	**2.50**		2.76	2.68	2.47	2.38

3. In 1999 the American Society for Mechanical Engineers (ASME) commissioned the Hudson Institute, Inc. to conduct a study of mechanical engineering and to identify trends impacting the profession.[12] This 109-page report has two major sections, one dealing with external trends that potentially affect all of engineering. It identifies rapid technological change, demographic change, economic change (considering globalization), and social change as the major external trends. The second section looks at trends within the mechanical engineering profession and covers research findings, including several pages on what mechanical engineers will need most in the future – focusing on the engineer's changing world of work.

In reporting what tomorrow's engineers believe they will need most, those interviewed and surveyed were divided into three groups: 1) young engineers – college and the first decade of professional work; 2) practicing engineers with 11-20 years of experience; and 3) mature engineers – those with more than 20 years experience. The results are given in Table 5.

Table 5
What Mechanical Engineers Believe They Most Need (*only the top 3 in each category are listed)*

Category	Percent saying most important
Young Engineers With 10 or less Years of Experience	
Continuing education	18
Career development/counseling	13
Role models and mentors	12
Practicing Engineers With 11-20 Years of Experience	
Continuing education	22
Networking: job finding	15
Career planning and transition	12
Mature Engineers With More Than 20 Years of Experience	
Continuing education	19
New job finding/Career changes	15
Other benefits that companies will stop (health, pensions, etc.)	13

One message is strikingly clear – all age groups without exception consider continuing education the most important need for their future professional growth. Nonetheless, it may be surprising to some that even the mature engineers considered lifelong learning to be the most important..

4. The results of a comprehensive survey of the general public were published in a report entitled "What the Public Wants from Higher Education".[13] This survey involved random sample techniques involving telephone interviews with 1,124 adults about their interest in education and training beyond high school; experience with continuing education; views on distance education; and opinions about the performance of colleges, vocation schools, and universities. The report has a wealth of data in it, but here I will only mention one. When asked how they would spend $100 of taxpayer money, the respondents said they would spend $45 on teaching students on campus, $30 on off-campus education and technical help, and $25 doing research. It is noteworthy that these respondents said that off-campus education and technical help should have two-thirds as much money allocated to it as teaching on campus and, moreover, judged off-campus education and technical help activity to be more important than research.

Where Engineering Education is Going in the U.S. We live in a time in which the nature of engineering education is changing at unprecedented rates. Industries have logged in with their voice, both individually and through ad hoc organizations such as the organization started by Boeing called the Industry, University, Government Roundtable for the Enhancement of Engineering Education (IUGREEE).[14] Virtually all studies and analyses have given the same message – that engineering education needs innovation and reform . Although moving much too slowly, that reform is underway in the U.S. NSF has supported the reform movement with an investment in the engineering education coalitions and other engineering education programs to the tune of well over $150 million in the last decade.

Faculty Challenges in the New Millenium. Now I close with a look at major challenges for the engineering professor in the 21st century. The universities are struggling to become more efficient and cost-effective, and at the same time, respond to the pressure to improve. That pressure will only increase.

1. New opportunities in holistic engineering. Today's small engineering design team using powerful CAD/CAM tools, perhaps working at different locations through telecommunication, can now do more design work than a hundred or more engineers of decades ago. The number of engineers "displaced" by powerful analysis and design tools will only increase. Does this suggest a lesser need for engineers in the future? If the engineers of the future were to do only the same kinds of jobs that the engineers of the past have done, the answer would be "yes." But engineers of this new century will be serving a much broader range of industries and societal needs than in the past and, as a result, the demand can be expected to increase. The new "industries" will seek engineers with good analytical and problem solving skills, who are adept at modeling and the use of computers, and who understand technology in the broadest sense. The new opportunities are in the so-called service sector such as: banking and finance; entertainment/media; legal and intellectual property; management and consulting; marketing; and health care. More engineers will be participating in the so-called "new economy" jobs, although the "old economy" activities will always be important.

For the engineer to take advantage of these new opportunities, engineering education must become more holistic.[15] Engineering education has been based on an analytic (science) model. Future engineering education must become more integrative. Table 6 taken from Bordogna's writings provides an example:

Table 6
Components of the Holistic Engineering Education of the 21st Century

Analytic (Science) Model, 1960-1985	Integrative Model, 2000 and Onward
Vertical (In-depth) Thinking	Lateral (Functional) Thinking
Abstract Learning	Experiential Learning
Reductionism – Fractionation	Integration – Connecting the Parts
Develop Order	Correlate Chaos
Understand Certainty	Handle Ambiguity
Analysis	Synthesis
Research	Design / Process / Manufacture
Solve Problems	Formulate Problems
Develop Ideas	Implement Ideas
Independence	Teamwork
Technological – Scientific Base	Societal Context / Ethics
Engineering Science	Functional Core of Engineering

> ***The challenge:*** **The professor of tomorrow must see this expanded role for engineers and modify the engineering education process to meet these needs.**

2. Data/information transmission and manipulation. The single most important global factor driving the changes that will challenge the professors of tomorrow is the ever-increasing rate of data/information transmission and the increasing capability to create new knowledge and uses for it. The rate that information can be transmitted has increased by many orders of magnitude and new tools have been invented to handle its volume. As a result, it is now possible to transmit millions of bits of information per second, e.g., all the information in the Library of Congress in 20 seconds and subsequently make rational use of it.

Education has been a process of transferring knowledge, information and techniques to a student. The professor's knowledge has traditionally been shared verbally and visually with the sitting (perhaps dozing) student. This process is not likely to satisfy the future student's quest for learning. Students now can get the information they need at the time they want it, and from wherever they want it. So the university and the professor in the next century will have to adapt to student desires regarding learning – or these future students will go elsewhere for their education.

> ***The challenge:*** **The professor of tomorrow must adapt to the learning styles of the individual students, not focus on her/his own style of teaching.**

3. Virtual university. We think of universities as a place with buildings for classrooms, a library, and places for students to congregate. Historically, the university has filled two roles – a place of learning university subjects and, also, a social institution. The traditional university as we know it today will likely continue as a social institution, but it will not be the only place for learning and advanced education.

Virtual universities will proliferate in the next century. Several are now emerging such as the National Technological University in the U.S., the United Kingdom Open University, and in Italy an education television network operated by 60 existing universities. Sir John Daniel, Vice Chancellor of the UK Open University indicates that the institution has 160,000 students in degree credit courses including 30,000 in its masters level graduate school.[16] It has 1500 research degree students (presumably PhD students). Access is as close as the nearest online computer and the cost is modest compared to the residential universities.

> ***The challenge*:** **The professor of tomorrow must adopt a more innovative and entrepreneurial approach to education. Education is big business and those who cannot or will not change to meet the student's needs will be displaced.**

4. Career-long learning. The university of the past has focused on providing college degrees for their students. While the degree is a measure of achievement and mastery at a certain level of knowledge, the student of the future will be more interested in relevant knowledge than the degree. Recent surveys clearly indicate that engineers in industry who desire continuing education are most interested in knowledge that is immediately relevant to their work and not another degree, *per se*. In the future, universities and faculty will have to address this fact of university life.

> ***The challenge:*** **Although lifelong learning is essential for continuing success, there will be many suppliers of this continuing education service other than the traditional university. Those professors who do not accommodate the needs of practicing engineers will not be involved in lifelong education.**

5. Cost of education. The cost of higher education has been rising faster than the national inflation rate and there is great political pressure to reduce the cost. The 'faculty salaries' category is by far the largest item in a university's budget. And that is the budget category that political leaders and university governing boards will look to cut.

> ***The challenge*:** **The successful future professor must always be cognizant of the cost of education and strive to use technology to reduce costs. If costs are out of control then virtual universities will flourish and fewer professors will be employed.**

6. Practice oriented degrees. In the past most graduate degrees in the U.S. have been focused toward research and scholarly achievement. Up until now we have focused on educating graduate students to fill university or research positions.

> ***The challenge:*** **Professors of tomorrow must look at the market and determine what the customers (the students) want. The immediate relevancy of the coursework to the person's professional goals will become increasingly important. The professor of tomorrow must focus on student needs and not his/her personal desires.**

7. Tenure. Tenure is unique to education and the judiciary in the U.S. Politicians in a democracy do not have tenure nor do employees in industry. The concept of academic freedom is very important and must be protected, but in democracies such human freedoms are protected for most citizens. If tenure is perceived as guaranteed employment for life regardless of performance, it will be abolished at some time in the future.

> ***The challenge:*** **The professor must focus on productive high quality work and not the protection and security of tenure. Engineering faculty members who are sensitive to changing educational needs and respond to them will have security through their own productivity and effectiveness**

A Final Comment on Change. An organism (or organization) that cannot adapt and change in response to environmental change will become extinct. Engineering educators must become more flexible. We must provide the solid, integrative engineering education program that enables graduates to continue to learn and adapt to the inevitable, but unpredictable changes that will occur in the practice of engineering.

> It is not the strongest of the species that survives, nor the most intelligent, but the one most responsive to change. – Charles Darwin

I have not talked on the move of private enterprise into the big business of education, but a few comments are in order. In an article in the Economic Viewpoint section of the December 27, 1999, issue of *Business Week,* Gary S. Becker, a 1992 Nobel Laureate from the University of Chicago, speaks to the issue of how the web is revolutionizing learning.[17] He states, "Modern economies require that people invest in the acquisition of knowledge, skills, and information throughout most of their lives." Becker, who has become involved in a for-profit company that specializes in online courses, predicts that soon there will be a global movement in online courses. This will be particularly so for highly skilled professionals. Somewhat in a follow-up article on the subject, *Business Week* two weeks later analyzed the for-profit, private enterprise education movement.[18] Mike Smith, Acting Deputy Secretary, U.S. Department of Education, is quoted as predicting that in 2000 "dot.com will come to higher education in a way no one could have imagined even three years ago." Smith further predicts that by this fall there will be tens of thousands of college courses on the Internet instead of the mere thousands today. The International Data Corp. figures that corporate e-learning, which had a market of $550 million in 1998, will explode to $7.1 billion in 2002.

The key question is what will the role of the universities be in this whole picture? At the 1999 Annual Conference of the European Society for Engineering Education in Winterthur, Switzerland, Professor Evan Petty of Limerick University in Ireland reviewed changes that must occur in engineering education in the coming decade, including those related to distance learning.[19] On the issue of private enterprise in higher education, Petty quotes Michael Milken, Chairman of Knowledge Universe, as saying in relation to universities:

> "… you're in an industry which is worth hundreds of billions of dollars, and you have a reputation for: 1) low productivity; 2) high cost; 3) bad management; 4) no use of technology. We're going to eat your lunch."

There will no doubt be an increasing business from the community of employed engineers who know they must be committed to continuous learning through life. The pressure will build to have universities play an increasingly important role in this endeavor. We must better organize to meet the challenge. Otherwise, Milken may be proven correct.

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