Reflections on the need to rethink the education of the engineer

A Presentation By
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Abstract: There are important forces driving changes in the engineering curriculum. These include (1) global economics, (2) rapid diffusion of information, (3) technology, (4) the convergence of disciplines, and (5) the need for the education of the complete professionalism for today's field. We are reflecting here on these forces, and we are proposing a vision that clearly directs us to desired outcomes in industrial practice and engineering education. This will lead to specific recommendations.

Engineering education must occur in context of international changes, and in consideration of the role of the engineer as a systems integrator, leader, manager, entrepreneur, and innovator. Increasingly, the engineer plays a key role in responding to the rising aspirations of people everywhere for a better life. This greatly enhances the professional components of the engineer's role.

The context for engineering education includes economic and social factors, as well as changes in technology and the magnitude of the complexity and multidimensionality of the problems to be solved. These result in the need to significantly broaden the education of the engineer, and balancing achievement of diverse outcomes while maintaining a reasonable course of study.

A number of recommendations are proposed. These include such considerations as the use of technology to bridge gaps between the classroom and the real world, providing for clinical experiences in international as well as national companies, and improving cooperation and collaboration in the development of engineering education efforts.

Keywords: engineering, education, globalization, curriculum, professionalism

Introduction

It would seem a tautology to state that the role of the engineer in the year 2000 and beyond *and* the engineering curriculum ought to be in harmony. We have every indication that you are working on this task and worrying about this challenge. This is clear from the titles of the papers you are presenting. There are numerous examples drawn from the topics of papers in other conferences dealing with engineering curricula throughout the world that also indicate that engineering curricula are in flux. We are reflecting here on the forces driving engineering curriculum changes, and we are proposing a vision that clearly directs us to desired outcomes in industrial practice and engineering education. This will lead to some specific recommendations regarding the engineering curriculum.

Engineers play a key role in responding to the rising aspirations of people everywhere for a better life. Engineering curricula are influencing both the more developed and less developed economies, as all are fueled by the dynamics of the marketplace and are making the transition from “imitators" to “initiators.” They needn’t go through every step from the industrial revolution to the present. They can learn from the mistakes and the accomplishments of the more developed economies and recognize that good economic policy and good social policy can go hand in hand. And they know that today’s innovation is tomorrow’s commodity, so that there is an ongoing need to innovate. The diffusion and the deployment of knowledge are so rapid that there is little time to sit back and admire our successes. There is information exchange and joint research and development occurring across national boundaries everywhere.

We have learned that global economic movements do not need to be a zero sum game, so that we can be participants in an inspiring movement to raise the living standards and quality of life of all people. This fundamental view of the role of the engineer in economic and social changes that are evolving across the globe must be reflected in the manner in which we educate and prepare engineers of the future.

Driving Forces

1. Global Economics

Understanding of the key influences on change lays the groundwork for the engineering curriculum; our graduates must be well-versed in factors associated with these forces in order to acquire needed perspective on engineering relationships to these forces. I will cite factors that years ago did not enter our thinking when we designed engineering curricula. The new factors deal with

- global economics
- speed of communications
- wider access to information
- a “raised bar” with regard to the complexity and multi-dimensionality of the problems to be solved.

Given the close connection between the engineering profession and economic development, the overriding influence upon engineering curricula must be the sweeping developments in science and technology that are influencing our economies. Simply put: technology and innovation are the key drivers of economies of the developed nations and the emerging nations.

Let me reiterate that the computer, the Internet, and the aspirations of people are contributing to world economic forces larger than governments and not limited by national boundaries. Business activity is, in fact, creating a world with disappearing traditional boundaries. There are governments and there is business. And there are other forces at work. These include the need for environmental responsibility and the inevitable convergence of capability. That is, there are very smart engineers and other professionals being educated everywhere. Thus, developing nations need not go through 200 years of the industrial revolution in order to compete effectively today.

Innovation is taking place in engineering education globally as well. Just as corporate enterprise has developed means of sharing the costs of research and development, cost sharing concepts are also developing in relations between and among engineering institutions as they enter into various cooperative agreements.

2. Rapid Diffusion of Information

We are all, to varying degrees, caught up in a technological movement that is shaping the world of production, communications, health systems, educational delivery, transportation, and more. Much of what is happening can be traced to basic research performed since the end of World War II, and this reinforces the critical and continuing role of research. Change is happening so rapidly, due to the incredibly rapid diffusion of information, that it is difficult to tell whether we are witnessing an evolution or a revolution. Most importantly, our concerns as professionals are increasingly set in a global context. The reach of business and the influence of communications are such that national boundaries are not nearly as important as they used to be. One might even argue that national interests are becoming blurred, and are giving over to international interests. There is a clear need to view engineering education within the framework of the global "revolution," and to see quick and ambitious changes in the engineering curriculum that respond in time to prepare our students adequately.

3. Technology

As I see it, we have multiple rapidly converging streams: one is the change which technology is bringing to the marketplace, and this is in varying degrees influenced by how we prepare technological professionals for practice. Applications move with extreme speed from research through development through product design and manufacture through distribution to the consumer market. The first version of a new audio component, a new cell phone, a new medical device is usually attractive and usually operates well. It is not the clunky first version of decades ago. With the expected number of failures, pretty much whatever one can imagine can be designed. Technology also, of course, influences how we teach and learn, how we deliver educational services. And, it influences what we attempt to teach and learn. So we have at least two rapidly converging streams: the effect of technology on the curriculum and the influence of the curriculum upon the development of new technology. How do we teach and learn under these circumstances?

4. Convergence of Disciplines

At the same time there is a blurring of the disciplines, a blurred line between science and technology, a convergence of technologies to produce new technologies, and a much more rapid diffusion of knowledge while there is a dramatic expansion of knowledge. These are important developments that influence what we do as educators of engineers.

Engineering programs are increasingly crosscutting, requiring either the creation of entirely new departments of instruction and schools, or a matrix arrangement whereby crosscutting programs are offered across traditional departmental units. Examples of this might include those areas which are now exploding on the academic scene: Internet engineering, financial engineering, biomedical engineering, information technology.

We recognize the fact that many engineering schools encourage linkages of engineering curricula to minors or entire additional degree programs in management, and that engineers often rise to key management roles in industry. So engineering is indeed a superb undergraduate major for such roles, and we are advising, in this presentation, approaches for broadening the engineering vision.

5. Educating the Complete Professional

What we see are important trends in engineering education, more and more reflecting the convergence of the real world demands on the educated professional and the educational experience of that professional. More and more structured problems faced by the engineer can be automated, thus providing the engineering professional more time and energy to deal with unstructured problems, which in fact represent the real world. These problems are often ill-defined, multi-solutional and time dependent. We no longer are confined in the classroom or in industry to a single solution to complex problems involving dozens of variables. We can have many solutions from which we must select those which are optimal or most important under the circumstances. Thus the computer is liberating and fosters creativity and is far more than a rapid calculator.

In order to adapt and adjust to new engineering disciplines and to grow professionally, the requirements of contemporary engineering education will continue to include a thorough grounding in the technical disciplines, but now we expect a significant level of proficiency in dealing with unstructured problems. I believe that we must encourage and develop in engineers a natural inclination to anticipate and to lead change, and this will be influenced by a capacity to formulate real world problems without having to make over-simplifying assumptions.

We must ask ourselves how can we enhance or strengthen creativity? How do we inspire students and working professionals to act as agents of change? When we ask employers what characteristics they seek in leaders of change and anticipators of change, often we hear of the need to understand issues in a global context and to communicate effectively at all levels - not only at the technical level. Employers seek engineers with a deep sense of ethics, an ease in working with and the ability to form inter-functional, interdisciplinary teams and indeed to lead such teams.

We are told that the professional should have a skill base and knowledge of human behavior. In addition to this rich array of knowledge and skills, it is important for an engineer to recognize that which he or she does not know and to develop the skill to determine for a given set of circumstances who does know. And of course, while we are seeking the characteristics of this very accomplished individual, we should add that we seek an interesting, broadly educated person whose life will be influenced by literature and art.

Engineering Education in Context

I hope that my remarks are leading to a conclusion that more and more we need to educate in context. What does educate in context mean? Certainly not that we abandon our traditional focus on fundamentals that remain essential in baccalaureate education and in continuing professional development. By education in context I mean that our students and faculty must be aware of the technological and business context of their work. It is a fact that engineers are critically important in driving the knowledge based economy that is innovation dependent. Should not educators and students be aware of the broader role of the engineer as systems integrator, leader, manager, entrepreneur, innovator, and recognize a technology and market driven economy.

These are verities of economic development of which an engineer should be knowledgeable. The engineer is, or should be, close to the center of a set of interrelated concepts (e.g., economics, management, public policy) which deal with the work of the complete professional.

We have certainly covered a great deal of material and if one were to think about traditional course work as a mode of delivery - our suggestions would appear daunting, especially given the perennial cry of the faculty for one more course - one more course. If we approach engineering education as providing a series of courses to satisfy each new development and application, there will never be enough courses or enough time. If we treat education of the engineer as one which must treat of complex problems involving far more than ever before, then the process of engineering education becomes one in which the student is at once teacher and learner, as the faculty member also is teacher and learner. The teaching role, of course, encompasses course facilitator, mentor, and expert scholar and practitioner. Engineering education becomes an evergreen enterprise in which our principal concern is process. A process in which faculty member and student are always asking new questions. They are coming to realize that every real non-trivial problem requires consideration of trade-offs. For example, a simple question such as “what are the environmental consequences of electronic commerce? “ turns out to be quite complex if all of the variables and consequences are considered.

Applications to Engineering Education

There are many factors supporting the proposition that engineering education should be broader in scope and that the result will be the emergence of leaders in the new economy. Take for example, engineering as a factor in increased productivity. Clearly, increased investment in information technology can lead to streamlined organizational designs, that is, restructuring, and cost reductions in products and services. In a recent issue of Business Week Magazine, examples are given of how technology increases productivity at every stage of the business process: innovation, collaboration, design, purchasing, manufacturing, logistics, marketing and service. Each example given can be applied wherever in the world there is access to communications and the Internet.

But these innovations in organizational structure, products and services are not confined to a single national economy, but become to a very great extent a global property, crossing national boundaries as businesses and the professions create their own boundaries. Engineers have access to information through the Internet, which provides for increased communication of vital information not possible even a few years ago. Global internet communication can facilitate in-person meetings which set the stage for more effective communication and collaboration than would otherwise be possible.

The economies of nations advantaged by knowledge workers need not be subject to a zero sum game, but rather all nations can benefit from the fruits of increased productivity and increased knowledge sharing.

Recently, I had the privilege of attending a reception in honor of King Abdullah II of Jordan at the residence of the Governor of the State of New Jersey. The audience was composed primarily of corporate executives. What did King Abdullah speak about? He spoke about the development of a knowledge-based economy in Jordan. He distributed a plan entitled "Launching Jordan's Software and IT Services Industry." The King said that while he still did not have enough industry to employ all of the information workers in Jordan, his nation was performing high technology work for more developed countries currently suffering a shortage of information workers. The King also said that the problems of the Middle East would ultimately be resolved through the action of economic forces rather than political considerations. Somehow, our engineering students should be aware of the influence that they can bring to bear on the world.

How can the engineering curriculum better prepare an engineer for the world of innovation and economic development than now exists and that is likely to continue?

Recommendations

As educators, we clearly have a critical role in facilitating the transition of the role of the engineer in the economic development process. I say "facilitating" because so many engineering graduates make this transition quite well despite the curriculum. That is, we are dealing with bright individuals, with good analytical skills, and with increasing knowledge of the world. The question is whether we can do a better job, indeed, a much better job.

I hold that the education of the engineer benefits from immersion in the problems of the real world, that is, educating in context. This should also be part of the environment of the engineering educator. He or she should understand and be prepared to introduce the critical issues of sustainability, of complexity, and of critical importance, the need to coordinate the role of individuals from a variety of disciplines and backgrounds in the approach to a real world problem of product and job development.

We must help to imbue in the engineer-to-be the concept that he or she is undergoing far more than occupational preparation. Too often students will tell us that the reason they have chosen engineering is because they like to fix cars or because they think that it is a good way to earn a living. Both may be true, but far more importantly engineering is a calling in which a lasting contribution can be made to the betterment of the larger society.

All this is well and good, but we are in the business of producing real educational outcomes employing real faculty. We are also in the business of recognizing that motivating students and faculty to a given set of objectives is imperative. Otherwise, we will not attract the gifted individuals so urgently needed by our profession.

Experience teaches us that students learn through a progression of steps, which begin, not with the most abstract view of the economic systems in which we function, but rather with an application specific view. The task becomes ever more complex for the educator as the number of disciplines and cross-disciplines increases and as the rapidity of creation of these areas of activity increases. It is not practical and it is not desirable to pile more and more into the engineering curriculum. Nor is it practical or desirable to de-emphasize the fundamentals of science, mathematics, engineering and computing application in the interest of creating a global economist. But there must be a way in which we can teach at the discipline or cross-discipline level while we graduate a new cadre of engineering professionals far broader in their outlook than their predecessors. This will require extremely hard work and indeed work for a team of educational professionals to accomplish.

Let me cite a number of approaches that might be taken or are being taken:

1. The computer affords us an opportunity to build into the curriculum a virtual corporation in which we can simulate the real world of product realization, commercial application, marketing, finance, environmental sensitivity and more.

2. With support from a National Science Foundation ten-year grant and in partnership with six other colleges and universities, my university is working to restructure the engineering curriculum in what are called Fundamentals of Engineering Design courses. The intent of the courses is to introduce engineering to students broadly, and to begin the process in the freshman year, not waiting until they are sophomores or juniors. The courses apply what we know about best pedagogical practices and industry needs. Students work in teams, in a hands-on, applications-oriented curriculum. The curriculum is comprised of modules: Mechanical, Civil and Environmental, Chemical, Electrical and Biomedical Engineering. Each module includes some technical instruction, applications, review and design assignments. The design assignments are completed by student teams, with facilitation by the faculty. The student products are computer aided designs, written and oral presentations, alternative solutions, and the consequences (within context) of the proposed solutions. The initial evaluations of FED are very favorable, using measures of student retention in the engineering disciplines, academic performance and student satisfaction.

3. Industrial leaders can become members of the university faculty for defined periods of time. Clinical faculty can become as important in engineering schools as their counterparts are in medical schools.

4. Close cooperation of faculty can lead to the development of a coherent set of contextual examples in each course, in which the examples extend to the broader agenda we are discussing.

5. An industrial "study abroad" program can be introduced such as those offered by liberal arts and management programs, but with opportunities to targeted overseas companies, this to reinforce the global nature of the economy and to add a significant dimension to the broader education of the engineer.

6. Universities may wish to consider the introduction of the faculty industrial sabbatical to better acquaint faculty with the challenges of the competitive marketplace.

7. We can, as an organization, facilitate curricular modifications that ameliorate barriers to engineering student Readiness. An approach includes using the newly organized International Network for Engineering Education and Research (iNEER) as a platform for change through exchange of information. INEER is a newly-formed organization resulting from a resolution promulgated at the February 2000 meeting of the International Steering Committee of the International Conference on Engineering Education (ICEE). The goal of iNEER is to promote further progress in education and research through international partnerships and information exchange.

A colleague of mine suggests that the more universal themes discussed above need to be introduced gradually, throughout the years of undergraduate education. He refers to this as education with a "hidden agenda". Well some of it can be hidden, that is it can surface slowly over an extended course of study. Some of it can be overt through formal coursework.

This should make teaching and learning engineering more challenging to the faculty member and student, but also more interesting. Perhaps, by stressing the more comprehensive trajectory of the engineer and the context of the education, we will increase the retention rate to graduation.

What I am suggesting is being applied to varying degrees in some engineering curricula. We have internships, externships, and cooperative education. But I believe we need much more of what I will call a process of ***mutual diffusion***. By this I mean that the real economy is incorporated into the process of educating engineers by having engineering fundamentals sewn together by real world context and the process in which professionals outside of academe become a fundamental not incidental part of engineering education.

Another example of mutual diffusion is the establishment of internal *quasi corporations* composed of students, engineering staff and supervising faculty to take on a real corporate project challenge with bottom line consequences to the corporation.

I have cited but a few examples of what might be done to further broaden the education of the engineer without sacrificing the teaching and learning of tried and true engineering sciences.

I believe that through this process of real world diffusion, we will produce engineers far more capable of dealing with the unstructured, time variable, extremely complex problems of a fast moving global economy, and in so doing be better prepared to offer leadership across the disciplines.

Thank you for your kind attention.