Education and Careers 2000

How Shall We Satisfy the Long-Term Educational Needs of Engineers?

I. Introduction

It has often been said that “where you stand depends on where you sit.” That is, your views on an issue are a consequence of your experiences and position. Thus, in the spirit of full disclosure, let me assert up front that:

- my view is that the practice of engineering is rapidly changing, and that engineering education is not keeping up;
- my experiences are primarily in information technology (both in academy and industry), which, admittedly, has changed more rapidly than some other fields.

So, while I acknowledge that my views are colored by the rapid change I have experienced, I fear, nonetheless, that my colleagues in academy do not appreciate the rapidity of change in the practice of engineering or its implications for engineering education. The engineers we are training today will still be practicing 40 years from now. Are we preparing them for what they will be doing then? Is the whole system of engineering education—not just the undergraduate curriculum—organized to support today’s graduate for the next 40 years? I think not on both counts.

It is almost a cliché to talk about change—so much so that a passing reference to it becomes a substitute for serious thought about its implications. But the fact is that the practice of engineering is changing at about the same pace as the technology it creates. The cumulative effect is staggering. I carry in my briefcase a computer that is about 100 times the speed of ENIAC, the first electronic digital computer in the United States. ENIAC had 18 000 vacuum tubes, weighed 30 tons, and filled a squash court. The chip in my briefcase is embedded in a greeting card and plays a tune when the card is opened.

My father was a practicing mechanical engineer 40 years ago, and his practice was as different from that of today as ENIAC was from my greeting card. The space of design options was much smaller. The tools to explore that space were largely limited to physical prototyping. The constraints under which he operated were both fewer in number and simpler to satisfy; for example, words like *ergonomics* and *environmental impact* were not in his professional vocabulary. Product cycles were measured in years, if, indeed, they were measured at all. Global markets were mostly in raw materials. The engineering department he headed was not even in the same building as the marketing and finance departments.

The last major shift in engineering education, to the so-called “engineering science” model, came on the heels of World War II, and has stood my generation of engineers in good stead. But that was 50 years ago, and, while there are interesting experiments at many schools, the "center of gravity" of engineering education has not moved much since. It is now time to examine that center, and the most basic premises underlying the education system for engineers.

There are many aspects to this reexamination, and I do not pretend to have answers. My crystal ball is no better than yours. I am absolutely certain that engineering practice will continue to change. It will probably change more in the next 40 years than it did in the last 40. But I have no better view than anyone else of what it will change *to*. Indeed, in some ways, that may be the essence of the problem facing us. How do we design an education system that is responsive to changes that we cannot predict?

To begin to address this question, I here pose six challenges to engineering schools and their faculties.

A. Challenge 1: The First Professional Degree

Most professions—business, law, medicine—do not consider the bachelor’s degree a professional degree. Engineering does. Doing so, in my view, is a misrepresentation to both the student and the employer, and creates a number of deep problems. The standard engineering curriculum has bloated to over 130 credit hours and still does not cover requisite material. Companies typically invest one to two years in training to complete the job. Liberal education in the humanities is squeezed out, as are social and management sciences *needed* by the modern engineer.

If we project ourselves ahead 40 years and ask whether a four-year degree is adequate preparation for the practice of engineering as it will be then, most of us will agree that it is not. The challenge is how to get to a different model of the profession without disenfranchising current engineers or causing financial hardship for students.

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B. Challenge 2: Curriculum

The squeeze caused by treating the bachelor's of science as a professional degree leads to the bloat in the program. It also provokes recitation of the mantra: "the undergraduate curriculum should teach (only) the fundamentals." Everyone agrees with that. The rubber meets the road, however, when we talk about what *are* the fundamentals.

Since the adoption of the engineering science model, the fundamentals have been largely continuous mathematics and physics. But, as I said earlier, engineering is changing. Here are a few examples.

- Information technology (IT) will be embedded in virtually every engineered product and process in the future—i.e., the design space for all engineers will include IT. Discrete math, not continuous math, is the underpinning of IT. It is a new fundamental.
- Biological materials and processes are a bit behind IT in their impact on engineering, but they are closing fast. Thus the chemical and biological sciences are also becoming fundamental to engineering.
- Engineered systems are increasingly complex, and increasingly contain components from across the spectrum of traditional engineering fields. More knowledge of the full spectrum will be fundamental.
- Engineering is global, and is performed in a holistic business context. The engineer must design under constraints that include global cultural and business contexts, and so must understand them. They too are new fundamentals.

The challenge is that we cannot just add these new fundamentals to a curriculum that is already too full. We have to look critically at the current cherished fundamentals and either displace them or find ways to cover them much more rapidly.

B. Galvin, former CEO of Motorola, says that he has never seen a process that cannot be speeded up by a factor of two and improved in quality at the same time. That is the sort of challenge we should accept for improving engineering education.

C. Challenge 3: The Need for Formalized Lifelong Learning

It has been said that the "half-life" of engineering knowledge—the time in which half of what an engineer knows becomes obsolete—is in the range of two to eight years, depending on the field. The only way for an engineer to have a productive 40+-year career is to continually renew his or her education. Although an engineer continually gains job-specific knowledge in the process of doing a particular job, such knowledge tends to be narrow and specialized, while engineered systems on the whole are becoming ever more complex, and involve components from more fields. Continual, explicit, structured education is going to have to complement on-the-job training.

The notion of lifelong learning has not been part of the engineering culture, either among individual engineers or among engineering schools. Both have to change. Individual engineers have to take responsibility for their own careers, and part of that responsibility is to keep abreast of the "new fundamentals." Merely taking training on the latest technology is not good enough. The fundamentals learned in college are still fundamental, but they probably will not be the only ones in this rapidly changing profession.

Engineering schools have a responsibility as well. It is especially disquieting that continuing education is often relegated to schools other than the best, and increasingly to for-profit organizations. Unlike business schools, where the best of the best have embraced "executive training," and where the best faculty vie to teach these courses, the best faculty at our best engineering schools studiously avoid continuing education.

The challenge is to change both of these cultures—to make lifelong learning opportunities available from our best faculty and engineering schools and to make practicing engineers routinely avail themselves of these opportunities.

D. Challenge 4: Faculty Rewards

I do not want to engage in the teaching versus research debate. I believe (like most of you, I suspect) that teaching and research complement each other and that there is a high correlation between good teaching and good research. But in engineering education we have an additional problem, which I will address after first providing some context.

My favorite description of what engineers do is "design under constraint." We design things that solve problems, but not any solution will do. We must satisfy constraints of cost, size, weight, power consumption, heat dissipation, manufacturability, reliability, safety, ergonomics, environmental impact, and on and on. The list of constraints is very long. Finding the best design, the *elegant* design under such constraints is a *highly* creative activity—one of the most creative activities I know of, in fact. In many ways we engineers have more in common with our colleagues in the arts than we admit (or our stereotype portrays).

This common context of creativity highlights an important distinction—unlike engineering, every other creative field on campus expects their faculty to practice/perform. Even if you do not buy the argument that engineering is creative in the same way as art or music, you can look to the professions of medicine and law, which also expect their faculties to practice the field they teach. Can you imagine a medical school where the faculty was prohibited from practicing medicine?

Yet, this is not so in engineering.

Engineering faculty are, for the most part, judged by the same criteria as science faculty—and the practice of engineering is not one of those criteria. The faculty reward system recognizes teaching, research, and service, but not delivering a marketable product or process, or designing an enduring piece of the nation's infrastructure. The criteria for promotion and tenure make it hard to hire and reward people with such experience, even though it would be valuable for students. In many cases, even taking a sabbatical in industry may be risky for faculty because it does not contribute to the usual resume-building activities of an academic.

Of course, what you measure is what you get. For the most part our faculty are superb "engineering scientists," but not necessarily folks that know much about the practice of the profession of engineering.

Please understand that this is not a criticism of the current faculty; I am one of them, and I respect my colleagues greatly. Rather, it is a challenge to envision a *system* that enriches the faculty with a complementary set of experiences and talents and thereby enriches the education of our students.

E. Challenge 5: Diversity in the Engineering Workforce and Faculty

As everyone knows, white males will be a minority of the workforce early in the next century; if we want an adequate supply of engineers we must attract women and minorities. But I think there is even a deeper reason to diversify the engineering workforce—lacking diversity we engineer less well.

As I said before, I believe that engineering is a highly creative profession. Research tells us that creativity does not spring from nothing; it is grounded in our life experiences, and hence limited by those experiences. Lacking diversity on an engineering team, we limit the set of solutions that will be considered and we may not find the best, the *elegant* solution.

Thus, diversity is not an abstract social goal, but rather a pragmatic business issue. But it is not a problem that business can solve by itself; if we do not attract underrepresented groups to engineering schools, they are not available as employees.

Until recently, the percentage of our undergraduate classes from underrepresented groups was increasing, but that seems to have stopped and even reversed in some cases. Moreover, we trail far behind fields like law, medicine, pharmacy, the life sciences, etc., which have essentially achieved parity. Nor can we use the excuse that "the pool" is not there; 49% of the Massachusetts Institute of Technology's 1999 class are women, for example. As many women as men have the requisite high school math and science, and they have similar grades in them.

The challenge, then, is for engineering schools and faculty to *own* this problem, to set specific concrete goals, and to get on with it. Personally, I would like to see the goal be a doubling of the current percentages by 2007. There are many, proven interventions that make this achievable—we just need to make it a priority and *do it*.

F. Challenge 6: Technological Literacy in the General Population

In "real life," I have most recently been a professor at the University of Virginia, which was founded by Thomas Jefferson. Jefferson founded the university based on his conviction that we could not have a democracy without an educated citizenry.

I think he would consider the current state of his democracy to be dangerous. Technology is one of the strongest forces shaping our nation. Our representatives in Congress vote on issues that will profoundly affect the country, and often the roots of those issues are, at least in part, technological. Yet most of those representatives, and the people who elect them, are technologically illiterate.

Every person with a "liberal education" needs to be technologically literate.

I am, by the way, consciously choosing to say "technologically literate," and not just "scientifically literate." It is not enough to understand something of nature. It is critical that we also understand the larger processes by which we transform nature, creating what *can be*, and shaping a better, richer life. Whether the issue is storage of nuclear waste, environmental remediation of the Everglades, or privacy of information on the Internet, an informed discussion requires a level of technological literacy that is absent today.

The challenge to engineering schools and faculties is to provide courses for liberal arts majors that are accessible and interesting, with content that will enable students to function as informed citizens of a technological world. Engineering schools have not traditionally provided such courses, but in this technological age they have a deep *responsibility* to do so. They will not be the kind of courses we are accustomed to teaching; they will need to relate technology and the process of creating (engineering), to larger societal issues.

II. Concluding Remarks

After 50 years, it is time to seriously reassess some of the basic premises of engineering education. The long-term needs of engineers and *society* demand it.

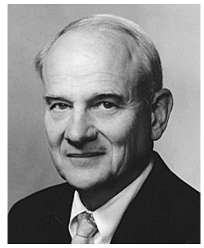
To keep up with the changes in both technology and engineering practice, we have tried to add content to a more or less fixed-size program—to put a ten-pound load in a five-pound sack. There are three possibilities for a resolution: to lengthen the program, to do more in the same time, or to make it continuous. In fact, we must do all three, and those are the first three challenges.

The issues are not all just quantitative, however. The qualitative, practical experience of "design under constraint" needs to become an integral part of engineering education, and we need to find a way to engage more faculty with personal experience in the practice of engineering. Likewise, we need to bring more diverse backgrounds to bear on engineering problems, to increase the creativity, and hence to engineer better. Hence the fourth and fifth challenges.

Last, we engineering educators must accept the responsibility for ensuring a technologically literate citizenry. To do that, we have to stop viewing the engineering students as our only responsibility, and we have to take the initiative. The humanities faculty is not going to come begging us to do something (they are often among the technologically illiterate themselves, and sometimes proud of it). Hence the sixth challenge.

There are other things that I could have raised as challenges, of course. Some engineers will not agree that these are the "big six" or that, in fact, they suggest desirable directions in which to move. They are, however, all issues that we need to examine, discuss, and reach consensus upon. I hope I have at least put them on the table.

William A.Wulf



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