An Urgent Need for Change

by Dr. William A. Wulf

MY PRACTICE IS TO SET THE CONTEXT for the NAE annual meeting with respect to an issue of importance to engineering. Even though I have taken a proactive position on NAE's involvement in reforming engineering education and even though I have spoken about it all over the country and written about it in journals, including *The Bridge*, I have never spoken about it to NAE members. Today I hope to communicate to you the urgent need I see for changing engineering education and to tell you what steps the academy has taken to promote reform.

There are lots of problems in the world, and engineering education isn't the only one NAE could focus on. I believe, however, that unless we have an adequate supply of gifted and creative engineers, we will not be able to solve the most substantive problems facing our planet. We will not be able to provide the benefits to the developing world that we have in the developed countries. Frankly, we will not even be able to maintain our current quality of life. The preparation of the next generation of engineers is, in my view, of the utmost importance.

I want to make three introductory comments before I launch into the main part of my talk. The first one is a caveat. I know that many schools are working on improving engineering education. I am going to paint with a very broad brush in my talk; I am going to create a cartoon. If I look down from 30,000 feet, the center of gravity of engineering education does not seem to have moved very much since I was a student. From this height, we can't see encouraging *points of light*, but I think we can get a correct overall picture.

Second, a word about my view of what an engineer does—namely *design under constraint*. I am particularly fond of Theodor von Karman's *[California Beta 1902]* remark contrasting science and engineering. "Science," he said, "is about understanding nature, understanding what is. By contrast, engineering is synthetic; it is about creating what has never been." Think about it! Creating what has never been. I believe engineering is enormously creative. It is design constrained by cost and size and weight and heat dissipation and power consumption and ergonomics and environmental impact and reliability and safety and on and on. Creating elegant designs under those constraints is one of the most creative activities I know of. Engineering is not *just applied science*. To be sure, knowledge of nature is one of our working constraints. But it is not the only one, not the hardest one, and almost never the limiting one.

Third, the practice of engineering is changing. Indeed, that is why I feel a sense of urgency about reforming engineering education. As global competition increases, we must engineer in a global, cultural, and business context. New designer materials, for which you can prespecify the properties you want, make the design space infinitely larger. Information technology will be part of every product manufactured in the future—it will simply not be cost effective to build "dumb" products any more. These and other forces have irreversibly changed engineering, and, if anything, the pace of change is accelerating. To be competitive in a globalized economy, to ensure that the quality of life in this country continues to improve, we must educate engineers for the jobs that will be, not the jobs that are or were.

Now that I've set the context, there are four points I want to make: (1) why I feel a sense of urgency; (2) what has to change; (3) why things aren't changing (faster); and (4) what NAE is doing to bring about change.

AN URGENT NEED FOR CHANGE

First, why do I feel a sense of urgency? Let me tell you a bit about my personal history. After I got my Ph.D., I taught at Carnegie Mellon University for 13 years. I then founded and was CEO of a company for almost 10 years. Then, after a short detour through the National Science Foundation, I went back to teaching at the University of Virginia. The interlude in industry really shaped my views about the need for reforming engineering education. On returning to academe, I was struck by two things. First, the engineering curriculum was pretty much the same one I had experienced 40 years before. Second, it had little relation to what I had experienced in industry.

Of course, many things are changing simultaneously; there is a mosaic of individual changes. Like any mosaic, if you are too close, it is hard to see the overall pattern. If you can stand back far enough, an overall image emerges; in this case an image of startling change. That is why I feel a sense of urgency about changing engineering education.

NECESSARY CHANGES

So what has to change? The first things most people mention are curriculum and pedagogy. Many reports—from NAE, from the American Society for Engineering Education, from the National Science Foundation, from the Engineering Dean's Council—speak to these issues. So, I won't. Time is too precious.

The next thing that comes to my mind is diversity, a subject about which I am very passionate. The usual arguments for diversity in the engineering workforce are about simple equity and the demographics of our population, which is less and less white male. But I think there is a much more powerful argument. We will engineer better with a diverse workforce. We will find better, more elegant solutions to engineering problems if we work with a diverse team.

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That may startle you, but remember, as I said earlier, engineering is a profoundly creative activity. Researchers in psychology have looked into the nature of creativity. Although there is no absolute unanimity on the subject, there is a strong consensus that creativity is simply making unexpected connections between things you already know, between life experiences you have already had. Men, women, underrepresented minorities, and the handicapped experience life differently. Almost by definition, the life experiences of a diverse team are more varied and thus offer greater opportunities for making unexpected connections.

I could go on about diversity a lot longer, but I want to touch on other things that have to be changed: the decreasing retention rate; the notion of the baccalaureate as the first professional degree; the system of faculty rewards; and the lack of technological literacy in the general population. I could talk for an hour about each of these, but I can only touch on them lightly here.

The retention rate is, frankly, a disgrace! Depending on the data you use, only about half of the students who enter engineering programs finish in engineering. For a long time, I believed the comfortable myth that we were flushing out poor students. Unfortunately, I am an engineer and have to believe the data. And the data say that the students who leave are every bit as good as the ones who stay. They have the same GPAs, the same SAT scores, the same scores in math and physics. They had the same standing in their high-school classes. We are not flushing out poor students. That comfortable myth I wanted to believe in is just that, a myth.

If you are concerned, as I am, about the continuing decline in the number of students entering engineering and, consequently, the number finishing engineering, the simplest way to fix the problem is to reduce the dropout rate. Fortunately, as a number of schools have shown, this is quite feasible. It is not preordained that we have to lose half of our engineering students.

Now, let's talk about the baccalaureate as the first professional degree. Unlike engineering, most professions—business, law, medicine—do not consider the baccalaureate to be the first professional degree, which in my opinion, is a misrepresentation to both students and employers. Trying to squeeze 10 pounds of material (the engineering curriculum) into a five-pound sack (a four-year course of study) just won't work. On one hand, companies must generally provide one or two additional years of training to new graduates. On the other hand, liberal education is squeezed out; there is no space in the curriculum for the social studies, languages, and management material that modern engineers need to know.

I want to make only one point about curriculum. When we talk about reducing the curriculum, somebody always says, we have to *focus on the fundamentals*. Everybody agrees on that, but not everyone agrees about what the fundamentals are. The last major change in the engineering curriculum (made just after World War II) morphed engineering into what is now called the *engineering-science* model. Physics and continuous mathematics are the core fundamentals of that model.

In the meantime, engineering has been changing. Information technology will be a part of every product and process in the future, and discrete mathematics, rather than continuous mathematics, is the language of information technology. It is a new fundamental. Biological materials and processes are a bit behind information technology in terms of their impact on engineering practice, but they are catching up fast. Biology and chemistry—molecular biology and organic chemistry in particular—are also new engineering fundamentals. In addition, engineering is now practiced in a global, holistic business context, and engineers must design under constraints that reflect that context. In the future, understanding other cultures, speaking other languages, and communicating with people from marketing and finance will be just as fundamental to the practice of engineering as physics and calculus.

Obviously, we can't just add these new fundamentals to a curriculum that is already too crowded and still claim that the baccalaureate is the first professional degree. We will have to use a sharp pencil and make some very hard decisions about what, in fact, really is fundamental to engineering.

Science is about understanding nature, understanding what is. By contrast, engineering is synthetic; it is about creating what has never been.

–Theodor von Karman, California Beta 1902

SLOW RATE OF CHANGE

Now let's turn to faculty rewards. I do not want to get into the teaching versus research debate, because I believe good teaching and good research go hand in hand and complement each other. In my admittedly idiosyncratic career, I have very seldom found a good researcher who was not a good teacher, or vice versa. There probably are some, but they are not the norm. Recall my description that engineers "design under constraint," that engineering is a synthetic, highly creative activity. Now, please picture your home campus. What other creative activities do not require their faculties to perform? Art? Music? If you don't believe engineering is creative in the same way as music or art, think about performance-oriented professions. Lawyers and doctors are expected to perform. Can you imagine a medical school in which the doctors were discouraged from treating patients? Would you want to be treated by a doctor who was trained at such a university?

Yet, we actively discourage engineering faculty from practicing engineering. The promotion and tenure criteria for engineering faculty are the same as for science faculty—research, teaching, and service. Nowhere in that list is the creation of a product that someone will buy or an addition to the enduring infrastructure of our country.

What you measure is what you get. So, for the most part, our engineering faculty are superb engineering scientists; but they are not necessarily superb practitioners of the engineering discipline. At most engineering schools, it is hard to hire or promote an individual whose record rests on having produced a product in industry, as opposed to publishing papers in journals. Please understand, I am not criticizing my faculty colleagues. In fact, I "are one." I am criticizing a system that doesn't allow us to complement traditional faculty with people whose experience in the practice of engineering would be of enormous value to students. Of course, to close the loop, the faculty decide on the curriculum. Therefore, it is not surprising that many CEOs in industry are critical of current engineering graduates.

So why haven't things changed faster? I honestly don't know the answer, but I have a hypothesis—namely, that most faculty do not believe change is necessary. They are following the time-tested adage—"if it ain't broke, don't fix it." Unless you've gone through the cycle of academia to industry to academia as I have and unless you are standing back far enough from the mosaic of change, it is not obvious that things are "broke."

LACK OF TECHNOLOGICAL LITERACY

Most recently, I have been a professor at the University of Virginia—founded by Thomas Jefferson, who was enormously proud of the university. Only three things are listed on his tombstone—and founding the university is one of them (no mention of his being president of the United States). As Jefferson wrote many times, he believed you could not have a democracy without informed citizens.

Oops! We have a society profoundly dependent upon technology, profoundly dependent upon engineers who produce that technology, and profoundly ignorant of technology. I see this "up close and personal" almost every day. I deal with members of our government who are very smart, but who don't even understand when they need to ask questions about the impact of science and technology on public policy.

Every person with a liberal education must become more technologically literate. Notice, I said technologically literate, not scientifically literate. It is not enough to be able to name the various branches of flora and fauna, which is what our typical high-school biology course covers. Everyone needs to know something about the process by which the knowledge of science is used to find solutions to human problems. Everyone needs an understanding of the larger innovation engine that creates the wealth from which everyone benefits. Engineering schools have not usually offered courses in technological literacy. But I can guarantee that nobody from the English department will come to the engineering school and ask for such a course. We engineers will have to take the initiative.

NAE EFFORTS TO PROMOTE CHANGE

As I noted before, many reports have been published on curriculum and pedagogy, and I don't think NAE can add anything unique to them. The National Science Foundation has supported innovations in engineering curriculum, for example support for centers of engineering education. I don't think we have much to contribute there either. But before NSF activities can be widely adopted or the recommendations in reports acted upon, faculty will have to agree that change is needed. NAE has decided that we can make a contribution there! The activities we are engaged in are intended to say: "The National Academy of Engineering believes change is needed, and we value people who contribute to that change."

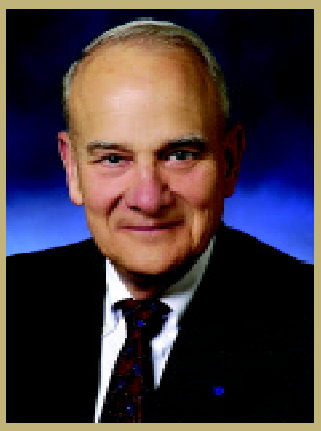
At NAE, we talk about my four-legged stool to affect change. Leg number one of the stool is to do what we always do—create a committee to conduct a series of workshops, studies, symposia, and so on, to focus attention on the need for change. Second, we made contributions to engineering education a criterion for election to NAE. How could we hold our heads up if we said that NAE values contributions to engineering education, but you can't be elected a member based on such a contribution?

Third, in addition to the two $500,000 prizes for the practice of engineering, the Draper prize and the Russ prize, we now award a third $500,000 prize, the Gordon prize, for contributions to engineering education. I'm sorry that Bernard M. Gordon *[MA B '48]* wasn't able to be here today, because I would have liked him to receive your applause. About three years ago, he gave us an endowment that allowed us to fund the prize every other year. He called it "the best thing I have ever done." Last fall, he decided to increase the endowment so that the prize could be given annually. So, beginning this February, we will give the Gordon prize every year.

Finally, NAE has established a center for the advancement of scholarship in engineering education (CASEE), which will complement, not compete with, the NSF centers. CASEE will support a group of fellows, National Academy of Engineering fellows in engineering education, who will be at the forefront of education research.

CONCLUSION

Our society is dependent upon technology created by engineers. Engineering is changing rapidly, and I believe engineering education has to change even faster for us to maintain our quality of life. We've studied it to death. We know what to do. So let's get on with it!



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He is on leave from the University of Virginia, where he is a university professor. His research spans computer architecture, computer security, programming languages, and optimizing compilers. In 1988-90 he was also on leave to be assistant director of the National Science Foundation. Prior to joining the faculty, Dr. Wulf founded a software company, Tartan Laboratories, based on research he did while on the faculty at Carnegie Mellon University.

Dr. Wulf is a member of the NAE, a fellow of the American Academy of Arts and Sciences, a corresponding member of the Academia Espanola De Ingeniera, and a foreign member of the Russian Academy of Sciences. He is a fellow of four professional societies: the ACM, the IEEE, the AAAS, and AWIS. He is the author of more than 100 papers and technical reports, has written three books, holds two U.S. Patents, and has supervised 25 Ph.D.'s in computer science.