
“The Urgency of Engineering Education Reform”

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Let me start by saying a little bit about the academies of engineering. I have come to understand that people have some strange ideas about the academies, so let me try to straighten them out.

What is an Academy of Engineering?

There are academies of science and academies of engineering all around the world. Except for in the former Soviet Union, they share two properties. First: they are not part of their government, but are private corporations. Second: they are honorific entities, that is, it is considered a great honor to be elected to one of these academies. You cannot join the Royal Society in London; you have to be elected by the existing membership. It is considered a very high honor, and recognition of a lifetime of contributions to science or engineering.

In the United States, our Academies of Science and Engineering share those two properties, but they have an additional one. In the middle of the “War of Northern Aggression”, that is in 1863, some U.S. scientists decided that we ought to have one of those honorific academies too. They incorporated what, at the time, was the National Academy of Sciences in Washington, D.C. It is now a 501-C (3), a “not for profit” corporation. If you remember your high school Civics, until 20 years ago the District of Columbia did not have a city government; the Federal Government acted as the city government. Articles of Incorporation, such as ours, were actually bills that went through the Congress (both House and Senate) and were signed by the President. The Academies make a big deal out of the fact that we operate under a congressional charter signed by Abraham Lincoln. Actually, the

truth is that any corporation formed in the District of Columbia in 1863 would have been congressionally chartered. However, something happened on the way to the forum. Somebody added about 42 words to what is otherwise an absolutely boilerplate corporate charter, and those 42 words changed everything. In modern English, they say that the Academy will provide advice to the Federal Government on any issue of science and technology, do so whenever asked, and do it for free. Therefore, with that addition, we became a schizophrenic organization. We have two personalities: personality number one is honorific; personality number two is an absolutely unbiased, absolutely authoritative advisor to the Federal Government.

Fast forward from 1863 to today — what started as one organization, the Academy of Sciences, is now actually four: The National Academy of Science, The National Academy of Engineering, The Institute of Medicine, and the National Research Council. I am going to lie to you a little bit because this organization is so complicated that I have to simplify. You can think of the first three as the honorific bodies, which then created The National Research Council, to be the operating arm of the honorific entities.

What does the Academy of Engineering do?

What do we mean by, “provide advice?” Well, the Feds come to us with a question, usually policy related, that would be better if informed by the current state of knowledge in Science and Engineering. We will put together a committee of ten to twenty people. They will be literally the best there are in the country on whatever the subject is. They will have no

conflict of interest and we will very carefully balance their biases. They will study whatever the subject is, usually for between three months and three years, although we do have two studies that have been going on for fifty years. Then they will write a report that I think of as a Ph.D. dissertation. It will be two to three hundred pages long, the last fifty pages of which are citations to the literature, and is fact based. There is not an opinion anywhere in it. It has also been peer reviewed by a set of people who are at least as eminent as the people on the committee that did the study in the first place. We produce one such report every working day. If you take a snap shot at any instant of time, there will be between six and ten thousand individuals working for free on these kinds of studies. There are five to six hundred studies in progress at any given time.

I just want to get across three points. One: we are both honorific and advisors. Two: we are not part of the government, although we are there to serve the government. Three: it is probably a larger activity than you thought.

By the way, every report is a public document and they are all posted on the web. We do a small number of classified studies, but even then, there will be an unclassified version of the report. So, if you look at www.nap.edu (NAP stands for National Academy Press), you will find out what kinds of things we have done this year. For example, Congress asked us about CAFE standards, the Corporate Average Fuel Economy standards. The Senate failed to pass the energy bill just recently, but it was our report that kicked off discussions about whether it is, in fact, possible to substantially increase average fuel economy. When President Bush de-

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Dr. Wulf giving the LITEE 2002 Distinguished Lecture.

cided to reverse the decision to reduce arsenic in drinking water, Administrator Whitman of the EPA asked us, “How much arsenic can we have in drinking water safely?” The answer, by the way, as far as we can tell, is none! These are just two examples – we put out one such report every day.

Need for Reform in Engineering Education

I really came to talk about the urgency of reform in engineering education. As you heard from my introduction, I ran a company for just shy of ten years, and then went back to the University. When I got back to the University, it was an “inter-ocular event” — like being hit with a two by four between the eyes. I realized how out of touch our engineering education is with the practice of engineering that I experienced when running a software company. It was very frustrating. We have studied the topic of reforming engineering education to death, the National Research Council produced a report, the National Science Foundation produced a report, the American Society for Engineering Education produced a report, but little of what these reports recommend has actually been implemented.

Points of LITEE

Let me make three points before I get started. The first one is a caveat. I am

going to paint with a very broad brush. There are some wonderful points of “LITEE” (pun intended) around the country. I think probably every engineering school has some kind of activity. However, when I get in an airplane and climb up to 30,000 feet, I try to integrate over what is being done everywhere and ask how different is engineering education today from when I was a student, so many years ago. The answer is, except that we do not teach drafting and surveying anymore, not much!

Difference Between Science and Engineering

Second, I want to give you a word or two about my view on what an engineer does, because it colors some of the other things that I am going to say. Science is analytic.

Science is concerned with understanding nature, with understanding what is. Engineering is about designing, creating solutions to human problems. It is about creating, as von Karmen said, “what never was”, but can be!

My favorite operational definition of what engineers do is, “design under constraint”. We design solutions to problems. However, there are a set of constraints that we have to satisfy — size, weight, reliability, safety, economic factors, environmental impact, manufacturability, reliability, and a whole list of “-bilities”. Engineering is *not* “just applied science”. It is an entirely different way of thinking. It is a profoundly creative discipline. By the way, in my experience, science (our knowledge of nature) is one of the constraints that we work under, but it is seldom the most stringent constraint, or the hardest one to satisfy.

Third point, before going on, I want to emphasize how rapidly the practice of engineering is changing — it’s one of the things that I learned when I started my company. It is that rapid pace that makes me feel so passionate about the need for reform of engineering education. I would like to think that engineering education keeps up with the practice of engineering, and therefore probably has to change at about the same pace. I might even like to believe that engineering education is “out in front” of where the practice is.

Unfortunately, I do not think either of those is true.

How Change Occurs

Sometimes the world gives us nice, monumental events that make crystal clear that change is happening. World War II is a marvelous example of something that cast an absolutely knife-edge shadow. You can talk about what engineering education was like before and after the war. You can talk about what the roles of women and minorities were before and after the war. You can talk about a whole series of social things that changed because of that monumental event.

Sometimes history is not so kind to us, and instead, change comes as a mosaic. One of the better examples is the Industrial Revolution. We talk about it now as though it was a point event. In fact, it smeared out over 100-200 years. Moreover, it was contemporaneous with the rise of rationalism, the rise of democracy, and profound fundamental changes in the nature of universities. If you were there at the time, you would not have called it the Industrial Revolution. They did not call it the Industrial Revolution because it was like pointillist art, individual pieces that create a pattern that you can only recognize when you stand back. I believe that today’s changes in the practice of engineering are a similar kind of mosaic.

Mosaic of Engineering

I am going to talk about six pieces of that mosaic. The first two are

- Complexity in the design space, and
- Complexity in the constraint set.

Remember, my quick definition of engineering was, “design under constraint”. Well, I am going to claim that both aspects of that — design and constraints — have become a lot more complicated and that fundamentally changes the nature of engineering. Then I’m going to talk about four other things,

- What I’ll call the fallacy of the possibility of precision,
- The expanded role of engineers in industry,
- The globalization of industry, and
- The fact that the pace of change it self is a change.

So, let me talk about each of those six

briefly.

Complexity of the design space

When you build a complicated system, you make many decisions. Each of those decisions can be thought of as a basis vector in a multidimensional space. Each of the possible choices for that decision is a point along that vector. I will just use the obvious examples: materials, information technology, and system complexity.

Materials: My Dad was a mechanical engineer, by all accounts a pretty darn good one. I can vividly remember he had a drafting table at home and on the shelf above the drafting was a little, thin volume that was a catalog of all of the kinds of metals that he could use. That was the total space of alternatives. Now we are talking about designer materials. You tell me what properties you want and we will create the material for you. The point is that the choices available to the engineer are much larger, making the size of the design space much larger.

Information technology (IT): This is my field. Moore's Law is not about to stop. There is probably another billion-fold increase in computing power and reduction in price possible. As a result, IT is going to be in everything. There will simply not be a product too pedestrian not to make it smart. Again, the size of the design space grows enormously as a consequence.

Systems: the number of components is getting larger and larger, and they are coming from different fields. There is an increased need for each of us to understand aspects of different fields. So the bottom line is, this design space has just become so much bigger, because of the choice of materials, the use of information technology and so on.

Complexity of the constraint set

My dad's constraints were mostly functionality and cost. It was pretty simple. The lowest cost design to achieve a certain functionality was it. Well, now we have safety, reliability, manufacturability, reparability, maintainability, and ecological considerations. I gave you a list before.

Not only is there a longer list of constraints, in many cases the optimization

function is much less clear. What are the units of ergonomics suitability, please? How do I tell whether this one is better than that one?

Some of the constraints that we work with are not easily measured and trade-offs are not easily allowed. As far as the general public is concerned, as far as I can tell, no ecological impact is permissible: none, zero.

So we have the design under constraint problem; where there are a lot more designs that you could choose from, there are also a lot more constraints and the optimization functions are not so obvious.

Fallacy of the Possibility of Precision

When my dad designed a machine, he built prototypes and he tested things. If his design did not work the first time, that was typical. His employer did not get mad at him. They figured he was a good engineer and he would get it right the second or third time. With modern computing and simulation techniques, and really very good models of the physical world, it is becoming increasingly possible to build the design in the computer and test it before you ever build that first prototype. Or, in fact, maybe you never built a prototype *at all*, as was done with the 777 and with most integrated circuits now days.

The possibility of precision allowed by simulation is a mixed blessing. It certainly is great to be able to design a hundred million transistor chip and have it work the first time. On the other hand, it is increasingly presumed by not only employers, but also customers, government regulators, insurance companies and a host of others, that any failure, anything that goes wrong is, in fact, an error on the engineer's part.

So here we are. We have a great big expanded design space, a lot more constraints, and a belief on the part of your employer, customer, and government regulator that you can get it right the first time. That implies the responsibility to examine the whole design space and consider all the constraints. It is not easy. Let me give you an example from my computer science background. I am going to teach you a little bit of computer science, if you will permit me.

First of all, have any of you (put your hand up) ever used a correct piece of software? I do not see many hands. Well, let me tell you something. If you can write a statement in first order predicate calculus that describes what you mean by correct behavior, it is possible to almost mechanically take that formula and back it up through a piece of software and derive another formula, which, if you can prove it is a tautology, then you have guaranteed that the program works correctly. You can reduce the issue of program correctness to that of proving a theorem. It is possible to be precise!

Why aren't we there? Why does Windows software have somewhere between a half a million and a million bugs at all times? Well, there is a practical issue. It turns out that theorem that you get out is huge. There are very practical problems in proving it. But, what is worse is that it is very hard to say what you mean by the intuitive notion of correct.

There was a study by the Naval Research Laboratory in 1993 in which they looked at fifty security flaws in computers. Most of you, I bet, think that those flaws derive from bugs. Well, the truth is that in 22 of the 50 cases, the problem was in the statement of what constituted correct behavior. When you get very complicated systems it becomes very hard to say, with precision, what you mean by "correct".

I believe that as engineering creates increasingly complicated systems, we are going to see this, not just in computer software, but also in all kinds of engineering. Then it becomes very, very hard to say what correctness is.

Expanded role of engineers and industry

I do not need to say very much about this. We all know engineering now is typically practiced in teams where the teams involve not just the engineer, but product designers, financial people, marketing people, sales people, etc. It has become incumbent on the engineer if not to be an expert in all those other areas, at least to be able to communicate, at least to be able to be a participant. Boy, does that ever have some implications for engineering education! It is really hard for most faculty to accept that "soft" ideas like marketing, might be as important to an engi-

neer as that next course in heat transfer. But the truth of the matter for the practicing engineer is that it is!

Globalization of industry

I won't say very much about this topic either, except to point out that once again we are going to be designing products and processes for a much more diverse audience, and some sensitivity on the part of engineers to issues of culture and language are increasingly important.

Pace of Change

And lastly, the pace of change in itself is a change. There was a workshop at the academy before I got there, so I heard about this indirectly. They were talking about the pace of change and somebody proposed a measure of the rate of change as the "half-life of engineering knowledge". In this workshop, they estimated that the half-life of engineering knowledge varied by field, but the limits they put on it were 2.5 years up to 7.5 years. So, half of what we are teaching our students in some fields (computer science, by the way, was the field of 2.5 years) is obsolete by the time they graduate.

What needs to be Reformed in Engineering Education?

I want to go back to my main topic, the urgent need for engineering education reform. What needs to be reformed? Well, the first three things that always come to mind are curriculum, pedagogy, and diversity, and I am going to say a little bit about those. But, I would also like to talk about the notion of the baccalaureate being the first professional degree, the faculty rewards system, the need for formalized lifelong learning, preparation of K-12 students, and technological literacy in the general workforce. That list is pretty long and the time is short, so I'm going to do this at warp speed. To start, I am not going to do them in the order that I talked about them, because they interrelate.

How long should the degree program be?

Let me start with the first professional degree. Every other profession treats at least a Masters Degree as the first professional degree. Engineering is the *only*

discipline that believes that the baccalaureate is a professional degree. I think the fact that we have not faced up to that causes all kinds of foolishness. Virtually every engineering degree is in the 130-140 semester hour range and, even at that rate, there is an awful lot we feel we ought to cover, but do not. Liberal Arts education background gets squeezed out and companies regularly presume that they will have to devote another year or two to the training of an engineer — which by the way, is really tough if you are a really small company, as I was. Social and management science topics are also squeezed out and this problem is really becoming acute, particularly in states like Virginia where they are about to mandate that the engineering curricula can be no more than 120 hours. The American Society of Civil Engineers has been extremely brave in being the only one of the engineering professional societies, which has said a Masters Degree should be the first professional degree.

Curriculum

The squeeze caused by treating the B.S. as the first professional degree leads, among other things, to the mantra, that I've heard as long as I've been teaching, that the undergraduate curriculum should teach only the fundamentals. I think everybody agrees with that. The rubber meets the road, unfortunately, when you start deciding what are the fundamentals. Let me just give you some examples. I do not think anybody will disagree that IT or biotech is going to play a major role in the future. Since the engineering science reform of engineering education after World War II, the "fundamentals" have been physics and continuous mathematics. Well, hello folks! Information technology is based on discrete mathematics, not continuous mathematics. Any kind of a serious use of IT in engineering is going to require all students to know some discrete mathematics. It's a new "fundamental".

For biotech, obviously, chemistry and biology are going to

become fundamental to all engineering. I also think the liberal arts, communication skills, and an understanding of global culture are fundamental to engineering as it is practiced today. Either we get rid of some of the old fundamentals, which I find impractical, or we have to start thinking about how we can teach smarter.

While I am on the subject of curriculum, let me speculate a bit about the topic of this business of the "possibility of precision". I think we are going to have to get comfortable with the notion that as we build increasingly complicated systems, we will not be able to predict all of their behaviors. That is what we see in complicated software systems. There are emergent behaviors that we could not predict. Notice I said, "could not predict", not just, "if you thought about it harder you would have predicted it." No, when systems get beyond a certain level of complexity, they will have emergent properties that you *cannot* predict. There are profound ethical issues raised by that. You probably know that the Corps of Engineers are "remediating" the Everglades. I cannot think of a more complicated ecological system than the Everglades. They have the hubris to think that they can predict all of the behaviors that are going to result from whatever changes that they make. It just boggles my mind.

Faculty rewards: Practice Engineering

I do not want to talk about the research versus teaching issue. I happen to be one of those who believe that good teaching and good research often go together. The good people are often just good. I want to raise a different issue. Remember my definition of what engineers do, "design under constraint"? I believe that engi-



Dr. Wulf with Dr. Sankar of Auburn University and Dr. Russ Pimmell of NSF.

neering is a profoundly creative activity — that problem of finding the *elegant* design is one of the most creative activities I know. All of you who have done engineering know this: finding an elegant solution is an aesthetic judgment as much as it is anything else. We are the only school on campus with creative professionals in it that does not expect our faculty to perform that creative activity. In music schools if you do not give recitals, you are not promoted. In art schools, if you do not create and show art, you are not promoted.

Even if you do not believe that engineering is akin to art or music, think about the performance oriented disciplines: law or medicine, for example. Would you want your doctor to be trained by people who had never practiced medicine? I do not think so. Yet, our engineering promotion criteria are essentially the same as they are for the sciences — education, research, and service. Nowhere does it say *practice engineering*. I think that is something that also has to change.

Diversity

Diversity is a big deal for me. I like to give many lectures on the subject; I am not going to do that tonight. The fact that is that we have failed, that we have stalled; women are now up around 19% of incoming classes nationwide, but they have been there for five years. African-American enrollment is dropping like a stone. The equity issue is a size-of-the-workforce issue, but I believe it is also a quality issue. We require diversity in the engineering workforce in order to engineer well. I can make a long argument for why that is true, but I am not going to it right now.

The need to formalize lifelong learning simply ties back to that half-life argument. We have to change into a mode like the medical doctors and other professions, where individual engineers presume it is their responsibility to get lifelong learning. Moreover, we, at engineering schools, need to provide it. I do not know about Auburn, but I can tell you that at the University of Virginia, the best faculty would not be caught dead teaching continuing education courses. Contrast this with a business school, where the best faculty vie for the opportunity to partici-

pate in executive training sessions. There is a culture change we have to go through.

Need for Technological Literacy for the General Public

In “real life” I am a professor at the University of Virginia. You may not know this, but Thomas Jefferson founded the University of Virginia. His home is just outside of town and he is buried there. He lists only three things on his tombstone, one of them being the founding of the University of Virginia. He was very, very proud of that because he said you cannot have a democracy without an informed citizenry. Therefore, education at all levels, and higher education in particular, in his view was essential.

We have a society that is totally dependent on technology but a citizenry, which is not only ignorant, but also *proud* of that ignorance. I go to a cocktail party at the university and somebody will ask me what I do. I say I am a professor in computer science. “Oh, I do not understand that stuff,” and they are proud of it. Therefore, I started a campaign. I go to cocktail parties and I ask people what they do. They say, “I’m a professor of English.” So I say, “semicolons, colons! I don’t understand that stuff.” I am consciously saying technological literacy, not math-science literacy.

The NAE went through an interesting exercise in 1999. Working with the professional societies, we created a list of the twenty greatest engineering achievements of the twentieth century.

Greatest Engineering Achievements of the 20th Century

The definition of the “greatest achievements” was not technological gee whiz, but impact on people’s lives. I have to tell you, I was stunned by the output. Number one on the list is electrification. What could you have done today if that plug were not in the wall? Number two and three were automobiles and airplanes,



Dr. Wulf with Dr. Raju and Dr. Benefield of Auburn University.

I can’t remember which order. I could not have arrived here today. Probably most of you could not live where you live if you did not have an automobile. Number four was clean water.

Did you realize that in 1900 the average lifespan was 46? Today it is 76, an increase of 30 years. It is estimated that 20 of those 30 years are due to clean water. The third leading cause of death in 1900 was water-borne diseases.

What Engineering Educators Need to Do?

I think that we engineers need to start owning the problem of technological literacy. I do not think we should allow a liberal arts student to get out of a university without some technological literacy. **We have tended to treat engineering schools strictly as professional schools. We do not offer “engineering for poets”, but we should.**

I am getting on toward wrapping up. My point has been that the practice of engineering is changing very rapidly and that engineering education has to change in a commensurate way. A fair question is what is the NAE going to do about it?

What NAE is Doing about Reforming Engineering Education?

Bill Wulf’s private analysis could be totally wrong, but when talking with individual faculty members, I sense a pervasive attitude that the “system ain’t broke”, that it does not need to be fixed/changed. The attitude is not a resistance to change, but rather a sense of what we’re doing is good, therefore it doesn’t need to be changed. The NAE is going to try to

change that attitude.

I have what I refer to as my four-legged stool of activities designed to change faculty attitudes. The first one is, we did what we always do, and we created a committee – the Committee on Engineering Education. We had five hundred committees so now we have five hundred and one. A consequence is that there will be a steady stream of workshops, of reports and additional information about engineering education reform. I created the CEE for two reasons: one is I really want the output, I want the reports, I want the workshops, I want people talking about the subject. But I also want to make it crystal clear that The Academy of Engineering values innovation in engineering education¹.

The second thing we did is more radical. We have made contributions to engineering education valid criteria for election to the Academy. When I thought about it for about four nanoseconds, I said “now wait a minute, how can we say that we value engineering education but you can’t be elected to the Academy for it?” So, you can now be elected to the Academy for contributions to engineering education.

Our third leg is a prize. The academy gave two major prizes for innovations in engineering, the Draper prize and the Rust prize. They were given for such things as the basic technology of the Internet, the jet engine, integrated circuits, Fortran, and so on. We now give a third prize, the Gordon Prize, which like the Draper and Russ Prizes carries a \$500,000 stipend; it’s for innovations in engineering education. We gave the first such prize in February during Engineers Week to Eli Fromm from Drexel University for what was called the E-4 project².

Those are the three legs of my stool that I’ve actually got implemented.

We are working on leg four of the stool. Normally the Academy writes reports that recommend that somebody else do something. Well, here we are going to actually do something ourselves! That something is the creation of a center on the scholarship of teaching and learning in engineering. We will invite visiting scholars to the Academy to spend anywhere from a semester to several years

working on the scholarship of engineering education.

There is a tremendous amount known about the way that people learn. The cognitive psychologists have made major strides in understanding both the physiological and psychological properties of learning. Very little of that has been applied to the pedagogy of engineering education. Again, we’re doing this for two reasons. One is, we want the scholarship that will result, but we *also* want what I think of as the “empty seat phenomenon”. When the faculty gets together for a faculty meeting and a chair is empty because Martha is at the Academy of Engineering working on engineering education, I want that to be a message to the rest of the faculty.

I hope you got the sense that I feel an urgency about reform in engineering education because that’s the message I came to give you. So, with that thank you very much and I’ll be happy to answer questions.

Questions and Answers

Question: What needs to change in the approach to education? How can we introduce more mathematics and technical information?

Answer: First of all, I guess I do not think it is a single thing that we need to do; there are a number of things that we need to do. I mean, I really do believe that we can teach smarter, in particular, if we would use some of what the social scientists and the psychologists have taught us about how people learn. There is no earthly reason to spend four semesters on calculus. Let me give you a data point. I spent about 4 years of my life at Virginia completely revising the computer science curriculum. When we got done, we went through an assessment process. To benchmark ourselves we actually tested our second year students against fourth year students from major universities including Stanford, Carnegie-Mellon, (which are two of the top three departments in the country), Georgia Tech, and U.T. Austin. Our sophomore students outperformed senior students at all those other schools, except one. It *is* possible to make quantum changes in the effectiveness of education.

Question: Who funds the National Academy of Engineering, how do you get funding?

Answer: It is a totally “soft money” organization. That is, every time the feds ask us for a study we negotiate a contract for doing that study at the university! The Office of Management and Budget deemed the existence of the membership organizations was a valid indirect expense in doing the studies. So, we do a volume of about 130 million dollars worth of these studies annually, and of that, about two million is devoted to supporting the membership piece of the Academy of Engineering. I have a little, tiny endowment that provides some additional resources, but it is so tiny it is hardly worth mentioning.

Question: Please comment on diversity within engineering education.

Answer: Well, here again, you are going to get Wulf’s theory. One of the things that has been well documented in a large number of studies, is that both women and under-represented minorities will preferentially choose positions where they can contribute to the welfare of others. That is precisely why law and medicine are at parity. It is why seventy percent of veterinary school students are women. The stereotype of engineering is that we do not improve the quality of people’s lives. We are nerds. We are Dilbert. (I hate Dilbert! I really do, I mean with a passion.) There are many facets of this, not the least of which is beefing up internship programs and that sort of thing. However, kids have to want to be engineers first, and we are losing market share. Women are staying flat as a percentage of the engineering enrollment. But it is really worse than that. The percentage of women in the university as a whole is going up. So, we are losing market share; even staying flat, we are losing market share. I think we have to ask ourselves, why are we repugnant? No, I do not think it is just advertising. On the other hand, do any of you recall the Bobby ad? It is an ad from a Swedish based company called ABB. A kid is in the classroom talking to his fellow students. His teacher is in the background. He is telling the other students how he is going to transform the world. He is go-

ing to solve the hunger problem; he is going to make everybody's quality of life better; he is so excited and at one point he is actually standing on the top of his desk. At the very end, the teacher says, "Oh Bobby, how are you going to do that?" He said, "I'm going to be an engineer for ABB". If we could get a lot more of that kind of advertising-making perhaps it would help. The main reason we did the twenty great achievements, was to try and drive home the point that engineers *do* help people. We do not have that one-on-one exposure. On the other hand, 90% of lawyers are sitting in some office reading contracts, they are not defending clients. There is an image, which differs from reality. We have an image that differs from reality in the wrong polarity.

Question: What could I, an engineering educator, do to change the status quo?

Answer: One of my heroes is Bob Galvin, former CEO of Motorola. Bob has said, "I have never seen a process which can not be speeded up by a factor of two, while simultaneously increasing the quality". I believe that for things like the teaching of calculus. We just haven't stood back and said, "wait a minute, how are we doing this? Is there a better way?" There is a long answer to that question. Go look at our Website. There is a report called "How People Learn," which is a place to start. Another of the things that we did is develop a set of K-12 science and math standards. Go to the Website for ITEA (International Technology Education Association). We also collaborated with ITEA to build a set of K-12 standards for technology as well. There are better ways of teaching that are known, inquiry based methods, in particular. Go talk to your school board, talk to your principal. Volunteer to go in and work in the classroom with kids. By and large, we have teachers who are not equipped to teach science and mathematics in K-12; they have a negative attitude themselves. And, boy, does that come through. They want to teach the stuff, but they are scared of it. They teach by rote from what the textbook says and the textbooks are often terribly wrong. There are some just grungiest examples of giving the wrong explanations for things. The other thing to do is for the engineering schools to

partner with the education schools, because the education schools teach the people who are going to teach the students. If change does not happen, the techno-phobia will just perpetuate.

Question: What outcomes did EC 2000 make possible?

Answer: I think fundamental change in engineering education would have been impossible without EC 2000. But EC 2000 does not make the change happen, it merely enables it. The other wonderful thing about EC 2000 is that it goes against the earlier bean counting scheme, where every engineering school in the country essentially looked just like every other engineering school in the country. Now a school has a chance to say, "wait a minute, this is the kind of engineer we want to produce and it is not the same as what the other school wants to produce". At the University of Virginia, we know that 2/3 of our graduating class will go to business school or law school. There is a self-selection process and yet we could not tailor our engineering curriculum to what would be best for such students. Now, if we have the courage, we can make the changes.

Question: I would like to see engineering education be able to introduce more cutting edge technology in the classroom.

Answer: It ties back to the issue of the B.S. being the first professional degree, I think. Okay, so we are all in agreement? Amazing! Thank you very much.

¹ Wm. A. Wulf, president of the National Academies' National Academy of Engineering (NAE), announced the appointment of Norman L. Fortenberry as director of the Academy's new Center for the Advancement of Scholarship on Engineering Education (CASEE) on Sept. 27, 2002. The center is a new initiative that seeks to catalyze continuous improvement in engineering education through increased attention to what is taught and how it is taught.

² Eli Fromm, Roy A. Brothers University Professor and director of the Center for Educational Research, Drexel University, Philadelphia, is the first recipient of the Bernard M. Gordon Prize for inventiveness in engineering and technology education. Fromm has implemented revolutionary ideas that are showing dramatic results in areas such as student retention and minority involvement in engineering studies.

Wm. A. Wulf is on leave from the University of Virginia, where he is a University Professor and AT&T Professor of Engineering in the Computer Science Dept., to serve as President of the National Academy of Engineering (NAE). Together with its sibling, the National Academy of Sciences, the NAE is both an honorific organization and an independent, authoritative advisor to the government on issues involving science and technology. Prior to joining the University of Virginia, Dr. Wulf was an Assistant Director of the National Science Foundation, responsible for computing research, the national supercomputer centers, and the NSFnet (predecessor to the Internet as we know it now). Prior to NSF, Dr. Wulf founded and was CEO of Tartan Laboratories, a software company in Pittsburgh. Tartan was based on re-

search Dr. Wulf did while on the faculty of Carnegie-Mellon University. Dr. Wulf holds a BS in Engineering Physics and an MS in Electrical Engineering from the University of Illinois and a PhD. in Computer Science from the University of Virginia. He has conducted research in computer architecture, programming languages, optimizing compilers and computer security. He is a Fellow of the IEEE, ACM, AAAS, AWIS, and the American Academy of Arts and Sciences, and is a member of the National Academy of Engineering.

