ASEE Keynote: The Urgency of Engineering Education Reform
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Thank you for inviting me to speak here today. I jumped at the chance because I want to talk about what *should* be a watershed change in engineering education -- but that hasn't happened. I hope to communicate to you the urgency I feel for the need for this change, as well as something of the nature of it.

They say "where you stand depends on where you sit", so let me say a few words about where it sit – namely at the National Academy of Engineering. You all know the Academy as an honorific organization. One cannot join the Academy; you must be elected by the existing members. Being elected to the NAE is generally considered the highest honor that can be bestowed on an engineer by his or her peers.

But, in addition to being honorific, the Academy (together with the National Academy of Sciences and the Institute of Medicine) was chartered by congress to provide authoritative, unbiased advice to the nation on issues of science, engineering and health. In fact, the NAE's mission statement says that we should be " … responsible for the technological health of the nation…". In that context, the NAE has become very concerned about the status of engineering education.

I should make three introductory remarks before proceeding.

First a caveat: I am going to paint with a broad brush. I know there are exciting, innovative programs in a number of engineering schools. Perhaps even most schools are trying one or two innovative things. My remarks will integrate over the field, and cartoon the overall state, thus will miss explicitly recognizing these "points of light".

Second a word about my view if what an engineer does, since this colors my view of how an engineer needs to be educated.

> science is analytic -- it strives to understand nature, what <u>is.</u>

> engineering is synthetic -- it strives to create what <u>can be</u>.

My favorite operational definition of engineering is

> design under constraint

Engineering is creating, designing, what can be -- but it is constrained by nature, by cost, by concerns of safety, reliability, environmental impact, manufacturability, maintainability -- indeed the long list of such "ilities". Engineering is *not* "just applied science". To be sure our understanding of nature is one of the constraints we work under, but it is far from the only one, it is seldom the hardest one, and almost never the limiting one.

Third, engineering is changing. Indeed that change is what underlies the urgency that I feel for a change in engineering education. Growing global competition and the subsequent restructuring of industry, the shift from defense to civilian work, the use of new materials and biological processes, and the explosion of information technology -- both as part of the process of engineering and as part of its product -- have dramatically and irreversibly changed the practice of engineering. If anything, the pace of this change is accelerating.

Although there are isolated "points of light", in general engineering education has not kept up with this changing environment. I think it is only a slight exaggeration to say that our students are being prepared for practicing engineering in a world that existed when we were trained, but not for the 21st century.

There are four parts to the remainder of this talk:
1. Why do I feel this urgency?
2. What needs to change?
3. Why isn't it changing (faster)? And
4. Some information on what the NAE is doing.

Why do I feel this urgency?

A bit of my personal history is relevant here. I taught at Carnegie Mellon for 13 years and then started and was CEO of a software company for just shy of a decade before returning to academia at Virginia (with a brief tour as an Assistant Director of NSF sandwiched between). That interlude in industry gave me a perspective that most academics don't have – and I was struck by how different the academic preparation of engineers was from what I had experienced. The practice of engineering has changed, but engineering education hasn't (not much anyway); with few exceptions, the current curriculum is the same as the one I studied almost 40 years ago. Ideally one would like to think that engineering education would prepare one for the career they will have and not the one their fathers had – but, alas, I don't think that is the case.

Many things are changing simultaneously in the practice of engineering. Together they form a mosaic of overall change – a mosaic that, perhaps, is not easy to see from close up. But if you stand back an overall pattern emerges that is startling in scope. I feel this urgency for change because I am afraid that we will soon be educating engineers that cannot compete, that cannot innovate in the way that has brought such prosperity to the developed world.

What needs to change?

A *lot*, I think! The first things that always come to mind, of course, are

1. curriculum
2. pedagogy

But you are all experts in these so I won't say much about them. The next thing that comes to mind is

3. diversity

and this is a topic that also concerns me greatly and that I would love to spend an hour on. Let me just say that in addition to the usual reasons given for diversity – namely equity and having enough engineers – I believe there is also an issue of quality. A diverse team will find better solutions to engineering problems. I wish I had the time to develop this point further, but to get back to my main theme I want to talk about four points that are perhaps a bit more controversial:

4. retention rate
5. the notion that the BS is the first professional degree
5. the system of faculty rewards, and
8. technological literacy in the general population

The list is long and the space is short, so I will say only a few words about only some of these to give you a sense of both the vector of needed change and why I feel urgency about it. I am also going to jump around in this list because they are not independent.

Retention Rate

It is a disgrace! Depending on whose numbers you use, something approaching half the students entering engineering do not finish with an engineering degree. Those who leave are *not* poor students; by almost every measure they are about the same caliber as those that stay. We are *not* "weeding out" the poor students! Rather, the poor retention rate is a measure of *our failure* to convey the pleasure and impact of engineering.

A few weeks ago there was an article on the front page of the business section of the Wall Street Journal that talked about the impending shortage of engineers in the U.S. The article started with a real life story of a young woman, an A student, who dropped out of engineering because she could not see how a career in engineering would contribute to society. I find that story deeply troubling. The truth is that engineering and the technology that engineering creates has had a profoundly positive effect on society.

If you are as concerned as I about the number and quality of engineers in the future[1], the quickest fix is simply to halve the drop-out rate … and we can do that by fixing the curriculum and pedagogy of engineering education.

The First Professional Degree

Most professions -- business, law, medicine -- do not consider the bachelor's degree a professional degree. Engineering does. Doing so is a misrepresentation to both the student and employer; to mention just a few of the problems this causes:

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[1] I was shocked to learn recently that at NASA there are three times as many engineers over 60 as under 30!

- the program has bloated to over 130 credit hours and still doesn't cover requisite material,
- companies generally presume that they need to invest 1-2 years in training to complete the job
- liberal education in the humanities is squeezed out
- as are social and management sciences *needed* by modern engineer
- the problem is exacerbated as a number of states mandate a maximum of 120 hours

These problems naturally segway into the curriculum issues. The squeeze caused by treating the BS as a professional degree leads to the bloat in the program, etc. It also provokes recitation of the mantra "the undergraduate curriculum should teach (only) the fundamentals". Everyone agrees with that, pretty much. The rubber meets the road when we get to talking about what <u>are</u> the fundamentals.

The last major curriculum change in engineering, a changed to what is referred to as the "engineering science" approach followed WW II. Since then the fundamentals have been largely seen as continuous mathematics and physics. But, as I said earlier, engineering is changing!

Information technology will be embedded in virtually every product/process in the future -- i.e., the "design space" for all engineers will include IT. Discrete math, not continuous math, is the underpinning if IT. It's 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.

Engineering is global, and engineering is done in a holistic business context. The engineer must design under constraints that include global cultural and business contexts -- and so must understand them at a deep level. They too are new "fundamentals".

We can't just add these "new fundamentals" to a curriculum that's already too full, especially if we still claim that the baccalaureate is a professional degree. We have to look critically at the current cherished "fundamentals", and either displace them or find ways to cover them much more rapidly.

Faculty Rewards

I don't especially want to engage in the teaching vs. research debate. I suspect, like most of you, I believe that teaching and research complement each other. And, by and large, there is a high correlation between good teaching and good research. Good people are good! In my admittedly idiosyncratic career, the number of cases of genuinely good teachers who were not good researchers is very small.

But, in engineering education I think we have an additional problem, and that's the one I want to emphasize. Recall, my definition of engineering is "design under constraint". I believe that it's a synthetic, *highly* creative activity.

Can you think of any other creative field on campus where the faculty are not expected to practice/perform ? Art, music, drama? Even if you won't buy that engineering is creative in the same way as art or music -- performance oriented professions such as medicine and law expect their faculty to practice that profession. Can you imagine a medical school where the faculty was prohibited from practicing medicine?

Yet, not so in engineering.

Faculty are, for the most part, judged by criteria similar to the science faculty -- and the practice of engineering is not one of those criteria. The faculty reward system recognizes teaching, research and service to the profession -- but not delivering a marketable product or process, or designing an enduring piece of the nation's infrastructure.

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 a lot about he practice of the profession of engineering. At most schools, for example, it's hard to bring someone onto the faculty who has spent the career in industry, even though such people would be extremely valuable to the students; their resumes simply don't fit those the reward system values. Sometimes it's even hard to get recognition for a sabbatical in industry.

Please understand that I am not criticizing the current faculty; I am one of them, and I respect my colleagues greatly. Rather I am criticizing a *system* that prevents enriching the faculty with a complementary set of experiences and talents. But, to close the loop -- of course the current faculty are the folks with the largest say in the engineering curriculum. It should not be a big surprise that industry leaders have been increasingly vocal about their discontent with the engineering graduates.

Technological literacy in the general population

In "real life" I have been a professor at the University of Virginia, which was founded by Thomas Jefferson. He founded the university based on the 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, and our representatives in Congress are called upon regularly to vote on issues that will profoundly affect the nation -- and whose roots are technological. Yet both those representatives and the people who elect them are, for the most part, technologically illiterate.

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

I am consciously saying "technologically literate" and not just "scientifically literate" because its not enough to understand something of nature, what <u>is</u>. An understanding of the larger "innovation engine", the process by which an understanding of nature is converted into what <u>can be</u> -- into a better, richer life -- is critical.

Engineering schools have not traditionally provided courses for liberal arts majors -- but in my view they must. These courses will not be of the kind we are accustomed to teaching, since they need to relate technology and the process of creating it, that is engineering, to larger societal issues. But the urban myth of engineers, whether faculty of practitioners, is in my experience just that -- a myth.

In a Bridge article in the Summer of 1996, analyzed some popular modern American history texts and discovered that most of them ignore the impact of technology on society -- yet nothing, absolutely nothing has had a more profound impact in the 20th century.

Why haven't things changed (faster)?

I don't *know*, but I have a hypothesis. That hypothesis is simply that the faculty don't believe that change is needed. They are following the wise adage, "if it ain't broke, don't fix it". If one hasn't had recent experience in industry, which I argued above that most faculty don't, and if the change is a mosaic in multiple dimensions whose pattern is hard to discern, then the fact that it's "broke" is not easy to see.

What is the NAE doing?

You in ASEE are the experts on curriculum and pedagogy and the NAE has little to add to those efforts. Rather we are trying, with a number of specific activities, to change attitudes among your faculty colleagues to make them more receptive to your efforts – to make them accept that change is indeed, needed. Changing attitudes is not easy and it will not happen overnight, but it's a role that, perhaps, only the NAE can play. In particular, I believe that a clear and consistent message from the NAE that

1. The NAE believes change is necessary, and
2. The NAE values contributions to that change

will, over time, change faculty attitudes. To that end, we are taking four concrete actions:

1. We have created the Committee on Engineering Education (CEE),
2. We have made contributions to engineering education a valid criteria for election to the Academy,
3. We have established the $500,000 "Gordon Prize" for innovations in engineering and technology education, and
4. We will establish a Center for the Scholarship of Engineering Education (CSEE) at the NAE.

The CEE will conduct studies and hold workshops on topics in engineering education; the first of these will be held this Fall and will examine what the engineer of 2020 (that is, a mid-career engineer graduating now) will be doing – and hence what we ought to be teaching him or her today.

It would be inconsistent to say that the NAE values contributions to engineering education – but that's not enough to be elected as a member – so we changed that!

The Gordon Prize now establishes contributions to engineering education on a par with engineering innovation as recognized by the Draper and Russ Prizes – all are $500,000 prizes awarded by the NAE!

The CSEE is not yet funded, but we're working on it. The idea is to have a number of competitively selected "NAE Fellows" rotating through the center from engineering schools, from the "learning sciences" and from industry. These fellows will propose scholarly projects and will work on them at the NAE for distribution to the entire community.

Concluding Remarks

To conclude -- our society is not only dependent on technology, it is addicted to technological change. If asked about the important events of the 20th century, most people will respond with the list of wars, the great depression, etc. But, if one contrasts the life of an average citizen in 1898 with that in 1998, the profound differences are all the result of the technology produced by engineers.

Engineering, the process by which our understanding of nature is combined with constraints to create artifacts and processes, is changing. Indeed it is changing very rapidly. Engineering education has to change too!

We have studied it to death, and while there are differences between the reports cited at the beginning -- and with my remarks here -- the differences are not great. Let's get on with it! It's urgent that we do so!

The NAE will support you in ASEE in any way that we can, and specifically we are doing a number of things to try to make your colleagues on campus more receptive to the innovations we all know need to happen. Let's hope that all this effort will soon pay off!