Engineering Education in a Changing World

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It is an honor to be recognized as an IEC fellow. The list of fellows of the IEC is truly remarkable, and I am humbled to be included in that company. The recognition for which I have been selected is in the realm of engineering education. This has been my passion, my life, and my career for the past 30 years at Purdue University, as well as through my activities with the IEEE and many other organizations. And so today I will talk to you briefly about some of the discussions that we are having in the engineering education realm.

I have been listening to some of the questions about changes in design, reluctance or eagerness to adopt new tools, how to balance management constraints, how to balance risk with wanting to be innovative. These are questions that we in academia are taking very much to heart. What will engineering careers look like in the future, and what are our responsibilities in preparing our students not only for graduation, but more important, for the 40 years after graduation? Trying to understand the university's role is very challenging and is somewhat different from how it has been in the past.

The world is changing in many ways. We continually ask ourselves whether our graduates are going to have the attributes and skills they will need for careers over the next 40 years. Some of the drivers for change are new technologies that are emerging at an incredible pace. In particular, the continued importance of multidisciplinary technologies is increasing the need to be able to communicate across disciplines in order to have effective system-level designs.

The rate of technological change is unprecedented and continues to accelerate. What are the implications of this? Globalization and the impact it is having on our educational thinking is on everyone's minds. There are also workforce issues that we are trying to understand. Interest in engineering careers among U.S. high school students is down 18 percent since 1991. What are the workforce implications of our slow progress on diversity? We are seeing engineering students working in fields other than engineering. Are we preparing them for careers when they perhaps will not stay in engineering? And last, but certainly far from least, what issues are raised from offshoring?

Right now estimates put the half-life of engineering knowledge anywhere from two years to seven years, although most people will settle on five years. I will tell you that if it is less than five, and certainly if it is less than four, those of us at a university start to get scared. This means that by the time students are finished, half of what we did for those first couple of years may or may not be relevant. This is a frightening thought. We must ask ourselves what parts stay relevant so that students' education is current not only on the day they graduate, but also after they graduate and get jobs.

Another projection from workforce analyses is that 90 percent of what an engineer knows will be available on a computer. So who needs to know it? It states that 60 percent of future jobs will require training that only 20 percent of the current workforce possesses. How do we deal with changes of those magnitudes?

Enrollment Trends

Figure 1 shows some national trends in enrollment. The black line shows the percentage of U.S. freshmen intending to major in engineering going back to 1983; the colored lines are breakdowns by race, ethnicity, and sex. We see a gradual decline in interest in engineering majors in the United States. All of the lines below the black line are the patterns for women in engineering, and all of them have a downward slope. The only lines with upward

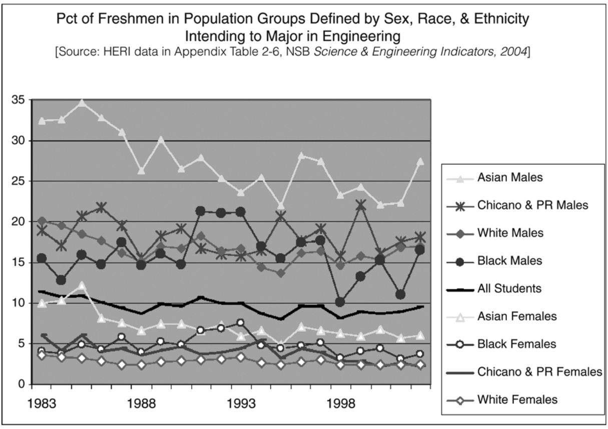

Figure 1: *U.S. Trends in Engineering Enrollment*

slopes are Asian males, and there is a fair amount of jumping around regarding African-American males, with some years high and others low.

There is a general sense that engineering is not as attractive in the United States as it used to be. We are trying to understand not only our role as educators in that perception, but also the role of industry. There are some global trends in the engineering market. I will simply say that the number of opinions about the presence of engineers in China, India, Russia, and the United States is as diverse as the number of people looking at these trends. There is very little agreement on the details of the numbers, but there is certainly an acknowledgment that if we look at both bachelor's degrees and what we call in the United States associate's degrees or technology degrees, there is an explosion of the workforce in China, a potentially growing workforce in India, and a stable or shrinking workforce in the United States.

I will also point out that, since the mid-1990s, we have made essentially no progress in the United States in the diversity of women and underrepresented minorities in engineering education or the engineering workforce. I will come back at the end to ask what this has to do with engineering education. Does it matter? I do think it is part of the picture, and I am going to talk about it later on.

All of these factors—globalization, the workforce, and the pace of change in technology—have spurred conversations in some sectors that consider engineering education. Probably the voices that have been the most coherent, and certainly the most reputable, are coming from the U.S. National Academy of Engineering (NAE) in a companion pair of reports: *The Engineer of 2020* and *Educating the Engineer of 2020.* The first volume sets out visions of what engineering will be for this century, and the second talks specifically about what the implications might be for engineering education.

A third NAE report, *Rising above the Gathering Storm,* which really addresses U.S. competitiveness in this world, also makes major recommendations relating to education. It points to education as one of the cornerstones for building a more competitive workforce. And certainly the many activities revolving around the American Council on Competitiveness initiative, Innovate America, talk about what we are going to do about education and what the implications are.

Changing Career Contexts

I would like to make some observations that emerged from the first *Engineer of 2020* report. The first phase, completed between 2002 and 2004, looked at the contexts, in particular the technological, societal, global, and professional contexts, in which engineering will be practiced. From those contexts, the report posited some aspirations: What will successful engineers look like? And from that, what are the attributes of those engineers? The second volume attempts to tie the conclusions of the first report to specific action agendas for engineering education.

So what are these contexts? The projected technological contexts are that there will be breakthrough technologies; enormous interest in biotechnology, nanotechnology, material science, photonics, information and communications technologies, as expected; and an information explosion.

The challenges will be where these technological contexts are applied and where they will have huge impact on urban infrastructure, overall information and communication infrastructure, and the environment. The technological contexts are really pulling in two directions because there are different population demographics throughout the world: technology for an aging population in the developed world and technology for a very young population in the developing world. And the rate of technological change is going to continue to accelerate. The amount of knowledge in these areas is doubling every five years and, in fact, will increase even more quickly. Solutions will be interdisciplinary, and complex systems perspectives are going to be essential for successful products in the future.

The discussions on the societal and professional contexts are much more wide-ranging. Population issues—the enormous growth, mostly in urban centers, but also the bimodal population of aging and younger populations in different parts of the world—are being discussed. Another societal context is an accelerating global economy, which means that market opportunities will continue to grow in many parts of the world. "Customerization" is another context—that is, made-to-order products for specific environments. There is enormous emphasis on health, health care delivery, and security. This report was done from 2002 to 2004. If it were done today, I think energy would be listed at the same level of importance and context as security and health.

There needs to be more interaction between engineering and public policy. Certainly we know this is true in telecommunications, but it will also be the case in energy, health care, and security. These are what we think of as hard-core engineering pieces, but they are also enormous public policy and public perception issues having to do with how you ensure safety and reliability. How these issues of safety and reliability are funded and which are adopted and which are not relate to public policy. Given the nature of these world-changing problems, this integration of engineering and public policy is going to become increasingly important over time.

There is a need for a global perspective of social contexts, perhaps even thinking about where engineering fits into the notion of liberal education. In the 19th and 20th centuries, liberal education meant liberal arts. Where does engineering fit into the liberal education for the 21st century? This is a question for those of us in education. What if every freshman at a major university with 38,000 students was required to know something about engineering? It certainly changes the way we have to think about what we are doing in the classrooms and what would make that relevant.

Changes in Education

From these contexts, the NAE report went on to identify a relatively small set of attributes, some of which are very familiar—communication, teamwork, business management skills, and ethical standards. Now we are also starting to talk about things such as practical ingenuity, creativity, dynamism, agility, resilience, and flexibility. It is fairly foreign for those of us in an academic setting, where we live by course curricula and outcomes, to be thinking about what we are doing to develop and foster those attributes. However, more and more studies, reports, and conversations are saying it is essential that we do so. These abilities are too important to wait and say they will show up eventually.

So how are we doing? Purdue has been addressing these issues for a few years and has set forth a vision for all of our engineering graduates. The vision states that they will be prepared for leadership roles in responding to the global, technological, societal, and economic challenges of the 21st century. We think not only about the attributes that the NAE has identified, but also about the many conversations with our faculty, alumni, and students. We are also looking into our engineering soul for what have we valued in the past, which things are changing, and which things are in fact going to be valued forever to understand the kinds of abilities and traits that we believe our students are going to need.

Abilities	Knowledge Areas	Traits
• *Leadership*	• Science and math	• *Innovative*
• Teamwork	• Engineering fundamentals	• *Strong work ethic*
• Communication	• *Analytical skills*	• Globally, socially, ethically, intellectually, and technologically responsible
• *Decision making*	• Open-ended design and problem-solving skills	• *Adaptable in a changing environment*
• *Recognize and manage change*	• Multidisciplinarity within and beyond engineering	• *Entrepreneurial and intrapreneurial*
• *Work effectively in diverse and multicultural environments*	• Integration of analytical, problem-solving, and design skills	• Curious and persistent lifelong learners
• Work effectively in the global engineering profession		**Key:** ABET a-k *Beyond ABET*
• Synthesize engineering, business, and societal perspectives		

Figure 2: *Attributes for the 21st Century*

To put this in context, in the late 1990s, ABET, the engineering accrediting body, developed a set of criteria originally called Engineering Criteria 2000, fondly referred to as ABET a-k. At that time, this represented a radical change in accreditation requirements. It meant educators had to look at things such as teamwork and communication skills. It was no longer about how much math you knew, how much circuit theory you knew, how much thermodynamics you knew. The new requirement said that students should understand and have experience working in teams, they should be good communicators, they should understand professional ethics, and they should understand the role of lifelong learning in their careers.

The black text of the Purdue attributes are fairly close maps to things we have been thinking about for a while. The middle column in the knowledge areas, this has been bread and butter of engineering education pretty much forever, but as you move away from that, we start seeing more purple text creeping in. And these are the attributes that appear to be emerging as critical this century but that we have really not made part of the engineering education process.

This brings us to some really serious questions. How are we going to teach? How will students learn all that is apparently necessary for careers?

Boeing for many years was known for having the attributes of an engineer, including critical thinking skills and, most important for Boeing, a systems perspective. *The Engineer of 2020* is now adding things like ingenuity, creativity, business leadership, and flexibility. No one I know in engineering education is ready to give up on the notions of technical depth and technical breadth. It is hard to be an engineer when you do not know the underlying math, science, and engineering fundamentals. And so we are faced with the question of how we do all this. We have increasing lists of things that apparently are going to be critical for our success, but where is the time to do it?

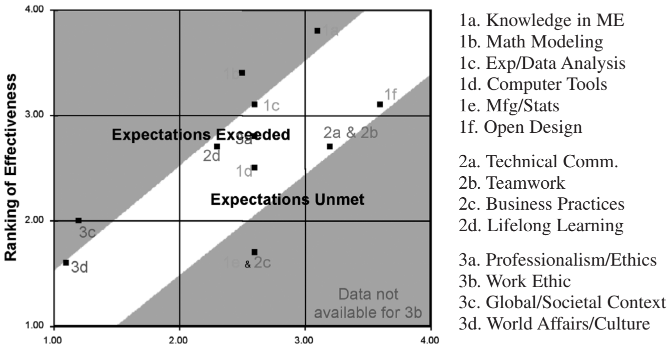

***Figure 3:** 1994 Purdue Mechanical Engineering Alumni Survey*

Figures 3 and *4* show data we collected from surveys of our mechanical engineering graduates from one to five years after graduation. The first survey, done in 1994, had some of the curriculum objectives that we were starting to move toward. Items 2a–2d are those things that were starting to emerge with the ABET criteria. Items 1a–1f are the pieces that have been in place for a long time such as knowledge of mechanical engineering, mathematical modeling, and computer tools. Items 3a–3d are those things that were pushing the envelope, especially in 1994. What we see, especially in the horizontal axis where the respondents were asked, Was this important? Has this been important in your career? We see that things such as work ethic, professionalism, global context, world affairs, and culture are hovering around the left axis. A few items are creeping over a little, but they were not part of the educational system. The rest of the items are spread out over the middle.

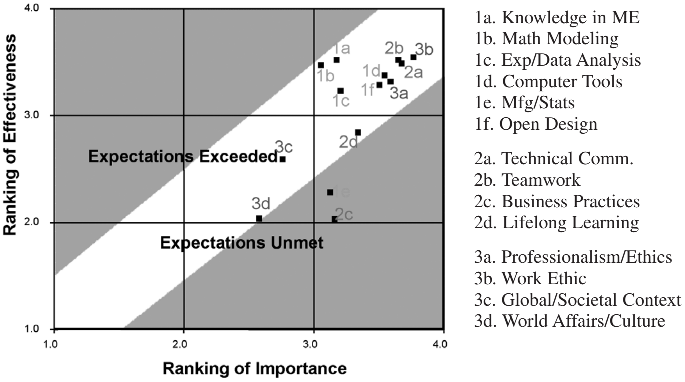

Figure 4: 2000 Purdue Mechanical Engineering Alumni Survey

If we look at the 2000 survey, everything has moved to the right. Every issue is more important. In particular, those global and societal contexts, the world, and cultural affairs that were down in the noise in 1994 are now in the middle of the pack, where most of the engineering attributes were six years previously. Those items previously in the middle have moved even farther to the right. What our graduates are telling us is that the list of skill sets and ability sets that they are going to need in their careers is growing, and that those things that were always important are now even more important. This brings us to the challenge of how can we do this?

The second volume of the NAE report, *Educating the Engineer of 2020,* makes two very specific recommendations. The first is that the bachelor's degree should be considered a pre-engineering or engineering training degree, that is, a four-year bachelor's degree is in some ways analogous to a pre-law or a pre-med degree. The second recommendation is that accreditation should extend to include the master's degree so that the master's degree becomes a professional degree in engineering.

These recommendations have caused enormous controversy in academia, in the industry, and from parents who will be paying for more years of education. The idea is out there with a very reputable stamp on it. The NAE says this is a good idea. Is it going to go that way? I am betting not, but it is certainly a topic of discussion.

An alternative proposal is to turn the curriculum inside out. The challenge is that we still need to teach engineering—technical and engineering skills—but now we need to teach this other stuff, and I contend that most of that "other stuff" is hard to teach in a traditional classroom. You do not envision a class on innovation; you do not envision a class on lifelong learning. So the question becomes, is there a way to turn the curriculum inside out; to integrate these other abilities so deeply that in fact they go along with the learning of the engineering?

The 20th-century curricula had engineering science at the core. It added fundamentals and engineering science, and toward the end, it probably included a design course—probably the best place to learn all of these other attributes. A possibility for the 21st century is to put the engineering experience at the core and wrap the engineering science around that core in support of learning how to design, solve problems, and do more open-ended engineering, even as an undergraduate.

These are very controversial ideas. There is no right answer here. I think the discussions are going to continue for many years, but they have to happen.

I am going to elaborate a little more on this idea of designing curricula around experience. There is a body of engineering education which is known as experiential education. This includes things such as co-op and internship experiences and service learning. It includes the notion of creating design teams that work in partnership with not-for-profits through experiences like the EPICs program. Entrepreneurship activities are gaining a lot of momentum in university settings, and undergraduate research and study abroad are essentially ways of learning by doing rather than learning by listening. The question is what do these opportunities really provide that go beyond the traditional settings?

We would like our students to be problem posers as well as problem solvers. We want them to walk into a room, listen to a discussion, see what is happening, and ask the right questions. We do not want them to wait to be handed a problem to solve. Think about the design process, which starts not with solving the problem that has been given, but with being able to back up and define what problem you should be solving. Then you must carry through with the implementation, delivery, testing, and second-generation design because you learn a lot from the first one.

How do we teach science and engineering fundamentals, analysis, and, for this industry in particular, tools, in the context of full-cycle design? Where do we teach these skills? Are they taught in courses, or do they come along with building real things and learning as you go?

There may be some efficiencies by doing this, by having students work on very realistic projects. We have an incredible diagnostic tool for the rest of our curriculum. Suppose students are in a design course, trying to build a circuit for something and we learn that they do not have a clue how to do it. We can go back and ask what we are doing in that circuits course, rather than waiting until the industry finds out that they have not learned it. We in academia can figure it out and then continue to refine our curriculum.

There are still many questions for which we do not have answers. What is the role of the university? What portion of this education actually is the responsibility of the university, either in an undergraduate degree or a graduate degree? And the complement of that, what is the role of industry? What portion do you learn on the job? What do you in industry expect when you get your degree or when you are hiring one of our students? Which is more important, for them to have experience with specific tools, or for them to have a more holistic problem-solving paradigm? Where does that tradeoff happen? Things such as innovation—can we do anything with that in the university or is that something that comes once students are on the job? How do we decide where the boundaries are between our job as educators and your job as employers?

In my role as IEEE president, I also question the role of professional societies. Lifelong learning continues to grow in importance. I think professional societies have an opportunity and are well placed to provide continuing education. Professional development must change as these attributes change. Professional societies are certainly well placed to become active in this very global realm.

As educators, we have a good idea how to teach circuit design, but we do not have a real good idea of how to teach innovation or how to teach flexibility. There is work starting in this. There are educators who are experimenting in their classrooms with ensuring that innovation is one of the attributes of a successful project. We are learning that there are things we can do, and we continue to work more closely with colleagues from other disciplines who have long known the importance of these attributes. We ask what makes people more or less innovative so our students will be more innovative the day they leave Purdue than when they got there.

Finally, I would like to come back to the diversity issue. Will different approaches to engineering education affect who becomes an engineer? For example, in some of the very experiential programs, international experiences, and study abroad engineering programs, the participation of women is twice as high as the participation of men or higher. In some cases, the participation of women is three or four times the participation of men in fields where 10 percent of the students are women.

International experiences are incredibly attractive to women. In service learning—projects that tie engineering to the community—two to three times as many women participate as compared to the base populations in their fields. So this notion of engineering in context—a very design-centered, experiential-centered curriculum—may give us different stories to tell elementary and high school students about what engineering and engineering curricula is like. There may be some implications between how we are teaching engineering and the question of who wants to be an engineer.

I think the last unanswered question is whether or not we have the courage to make such sweeping changes in education. It is a large system; we have talked about curriculum and thinking about it differently. Do we have the courage to change? Do you want us to change?

These are some of the discussions we in academia are having. It is an amazingly exciting time to be an engineering educator because the more questions you have, the more opportunities you have to do new and creative things.

I hope you will think about the issues raised here. What are the implications for you, for your job, for your young colleagues, and for the people you are going to hire? What do you expect from them? What are you learning in your own career? What is valuable? What is challenging? What is an educated engineer going to look like not only this year, but also 20 or 30 years from now? There are many opportunities, and I thank you for the opportunity to talk about it.

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