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Education of the Citizen Engineer

Where and how do you as an engineer strive to become a Citizen Engineer? Right now there is only one answer: through your own initiative. Although many schools are developing and evolving programs in engineering ethics and the relationship between engineering and society, there is no formally accredited curriculum at a university, no on-the-job training program at a corporation, and no comprehensive seminar or online resource.

In the meantime, there are things you can do. We'll assume you always are going to strive for excellence in your core engineering discipline; that's one of the hallmarks of a great engineer. To become more of a Citizen Engineer, we urge you to do the following.

- **Learn** the relationships between what you do and the broader social interests of the environment, safety and trust, security and privacy, choice, and competition.
- **Understand** the law and public policy. If you complain about the general level of ignorance others have about science and engineering, turn it around. What's your level of understanding about the legal and political systems?
- **Participate** in public dialogs regarding these topics. As an engineer, you bring skills and gifts to your local and national communities—from analytic reasoning skills to your constructive art. Think of these communities as your customer; listen, engage, and serve.

- Act on what you know and believe. Help to build innovation commons and vibrant communities that transcend your company and your country: Participate, contribute, grow, and help them.

We are unapologetically idealistic: That is a very full list. But if we are to lift our profession and truly help to lead humanity through this century—the century of engineering—we have to imagine the possibilities and work toward them.

At the core is education—expanding the very notion of what an engineer is and growing collectively who we are. Here's a brief synopsis of what schools are doing to facilitate the education of the Citizen Engineer, along with advice from some of the people we've spoken with in preparing this book.

With apologies to our global readers, we'll focus primarily on engineering education in the United States. While the primary education issues—especially the state of math and science education—may currently be unique to the United States, the broader analysis regarding university curricula is not. The education programs of U.S. engineering institutions continue to influence programs at universities worldwide.

Updating Engineering Curricula

> "The education system needs revamping. You're teaching the wrong stuff, which is why I'm on your case all the time. You're still teaching the system that is destroying the biosphere, and teaching the teachers to perpetuate it."[1]
> —*Ray Anderson, chair, Interface, Inc.*

That assessment was made several years ago by one of the leading advocates for industrial ecology and sustainability. Does it still hold true today? Yes and no.

Clearly, something about the way science and engineering are taught in the United States needs revamping. Over a 27-year period, from 1975 to 2002, the percentage of 24-year-olds in the United States who earned first Science, Technology, Engineering, and Mathematics (STEM) degrees increased by 43%; during this same period, that number quadrupled, on average, in Taiwan, South Korea, France, Spain, Mexico, and China.[2]

And according to a recent article from the National Academy of Engineering, "Overall, the number of engineering B.S. degrees earned by U.S. students peaked in 1985, steadily declined through 1992, and then came to rest on a decade-long plateau. The number began to climb again in 2002, but is still lower than it was in the mid-1980s. Coupled with a dramatic increase in retirements expected in the next two decades, these numbers signal a

national imperative that we attract more—and different—U.S. students to the engineering fold."[3]

If U.S. students are turning away from the field of engineering, it is incumbent upon all of us to ask why. One crowd says U.S. students don't think they can compete with the huge influx of engineering talent from Europe and Asia; another crowd says the bursting of the dot-com bubble has removed incentive because engineers can't make the quick millions anymore. We don't believe either of those things. We've seen no change in the number of very talented, technically savvy engineers coming out of U.S. colleges. They seem to get smarter every year, largely because of things such as open source software, which increase the volume of knowledge available to them.

Clearly, there are many reasons why the ranks of U.S. engineering students aren't growing as quickly as we'd like. One of those reasons, in our opinion, is that U.S. engineering schools are not fully tapping into the energy that's building around environmental and techno responsibility. Students really do want to change the world, and are very focused on making a difference in the critical global issues of ecosystem sustainability, health, education, economic opportunity, and human rights. Engineering and technology can have profoundly positive effects on all of these, but our schools have to be deliberate in making these connections, or else the best students will be attracted to other avenues.

To be fair, a growing number of engineering schools are beginning to recognize the growing importance of sociological, environmental, and intellectual property issues and are mixing these topics into the traditional curriculum. Better yet, some schools are introducing an interdisciplinary approach and creating new courses that attempt to broaden the field of study—and the perspective—of engineering students.

For example, at the MIT Sloan School of Management, Professor Steven Eppinger (currently deputy dean) has created an interdisciplinary product development course in which graduate students from engineering, management, and industrial design programs collaborate to develop new products.

"An interdisciplinary approach is important because that's what it takes to develop successful products," says Professor Eppinger. "In today's companies, innovation processes are collaborative and team-based. Critical inputs to product development come from many directions—engineering, sales, marketing, finance, even legal. Yet universities have traditionally taught in a stovepipe manner. We teach industrial designers separately from engineers, separately from business students, separately from lawyers, and we leave it up to the students to make the connections between the disciplines. For this new generation of young engineers, those interconnections are vitally important. If you're not content with designing just any old products but you want

to design products that really make a difference, engineers need to know something about business, about law, about the environment, so they will ask the right questions and seek inputs from other experts."

Many other schools are now preparing interdisciplinary courses or launching initiatives specifically focused on environmental engineering and sustainability. Here are some examples.

- Michigan State University offers a master of arts degree in environmental design, bringing a multidisciplinary approach to professional development, including acquisition of in-depth knowledge in the area of environmental design theory; development of problem-solving skills within an interdisciplinary professional context; development of technological expertise and knowledge base in a selected area of environmental design; and advanced ability in graphic, written, and oral communication skills.
- Cornell University now offers a minor in environmental engineering, encouraging engineering students "to learn about the scientific, engineering, and economic foundations of environmental engineering so that they are better able to address environmental management issues."[4]
- At Kettering University, a multidisciplinary engineering elective course employs proven pedagogical methods and tools that enable students to incorporate environmental and economic concerns into technical designs.[5]
- Virginia Tech offers a bioprocess engineering specialization, which combines knowledge of biological, chemical, and engineering principles to produce sustainable and environmentally responsible food, fuels, pharmaceuticals, plastics, construction materials, and other products from biological materials.[6]
- Introductory engineering courses at Michigan Tech now emphasize communication skills as a core element of engineering problem solving.[7]
- The College of Engineering and the Jackson School of Geosciences at the University of Texas jointly offer a degree program designed to teach students the geological and engineering principles needed to solve resource development and environmental problems.[8]

These and many other similar efforts are a step in the right direction. However, the shift to more broad-based, interdisciplinary, and/or environmentally responsible curricula has been painfully slow at many engineering schools.

"I've seen a trend toward more social consciousness both in process design engineering as well as in manufacturing processes, and that is beginning to be reflected in the curriculum here at Wisconsin and at other institutions," says Professor Harold Steudel of the Department of Industrial and Systems Engineering at the University of Wisconsin-Madison. "For example, our Department of Professional Development has introduced new courses on environmental management and sustainability. But it can be a slow and difficult process—both logistically and politically—to redesign [curricula] at major institutions."

Typically, change comes to the curricula at public universities through the efforts of a tenured professor or a faculty member with the energy and enthusiasm to push through new courses. And all too often the inertia outweighs the enthusiasm. So, what can an aspiring Citizen Engineer do? Here's some guidance.

Advice for Engineering Students

"You can learn to program and you can get a job fixing bugs . . . but if you want to do something that makes a difference, you have to learn to think across boundaries, to understand business, customers, law, public policy. . ."
—Mike Shapiro, Distinguished Engineer, Sun Microsystems

It can be a tough balancing act. If you broaden your areas of study while you're in engineering school, potential employers may consider you to be too unfocused. A triple major, for example, may actually be counterproductive. On the other hand, if you narrow your field of study, you may limit your growth—personally and professionally.

Good schools are starting to ensure that engineering students get deeper knowledge of how things work across traditional boundaries—for example, making sure that software engineers understand how a microprocessor works, how to write a compiler, how to write a program on top of that, and so on. Another dimension of this increased breadth is helping engineers understand how to analyze a market, how to explain the customer benefit of a new innovation, or what it means to have a great idea that has no channel to customers.

> *Today's responsible civil engineer must be aware not only of technical design issues but also of more efficient and "greener" materials, socially and environmentally responsible construction methods, and the need to collaborate closely with architects to achieve the best combination of art and functionality.*
>
> *—Ricardo Davila, MIT '06*

Here is one strategy that many people advocate for would-be Citizen Engineers: While in school, focus on getting that first job. Be technically savvy in your area of specialty, then broaden your base of knowledge and skill sets as your career evolves. Here's the problem with that advice: Narrowing down is very counterproductive in the long run. All the really interesting innovation occurs across boundaries, not within a specialty. For students, it's more important to get a deeper appreciation of interrelationships and to learn how to understand something that's completely new.

Our advice is to be as broad as you possibly can, especially as an undergraduate. Be sure to take courses in economics, business, political science, and law. Focus on how these areas help you *reason and think* rather than simply catalog knowledge. Legal reasoning, for example, is fundamentally different from what you are used to. Of course, logic does apply, but for many legal systems it is the history of the field in terms of case law, so-called *legal precedent,* that forms the underlying axioms. In these systems (e.g., in the United States), you don't argue what ought to be true or just; you argue how something relates to the case law. And for all systems, process is paramount—*how* something is decided may be more important than *what* was decided.

"Learn how to learn" may be hoary, but it's great advice. Learn how other people learn and reason too. Your best bet in influencing what happens in some other sphere, such as law or public policy, is to speak their language, rather than expecting them to speak yours. You will also be amazed how, later in life, you draw as much on your education in areas such as business, law, and ethics as you do on your core courses.

Advice for Engineering New Hires

"Don't just answer the question what are we building; ask what could we build?"
—Sheueling Chang,[9] Distinguished Engineer

One of the key concerns of many newly hired engineers is that they'll have very limited input into any social or environmental considerations of the projects they're working on. At the surface level, this often seems to be the case. If you're hired to optimize the firmware on a new board design for a mobile handset, management is not looking to you for guidance about the company's take-back policies. You have specific deadlines and deliverables. So, when and how do your values as a Citizen Engineer enter the picture?

In the words of Sun engineer Mike Shapiro, "If you're passionate about anything in your life, you're heading in the right direction. If you're passionate, you have to ask yourself: Am I willing to really learn my craft and learn

how to be a leader? If you are, you will notice two things: You will be able to engage in any activity or project and learn something by doing it, and you will become a better craftsman. A lot of people think what they're doing is unimportant. That's sometimes because they're not passionate; it's more often because they are passionate but they don't understand that what they're doing now will enable them to become a better craftsman and a better leader. If you're committed to being a craftsman, study the work of others. You'll learn how to be a leader, and you'll develop influence. No project is too trivial or simple to learn something valuable from."

Michael Falk, general counsel of the Wisconsin Alumni Research Foundation (WARF), adds the following: "As an engineer you have a unique set of abilities that so few of us have—the ability to manipulate what the real world looks like. Whatever your role is, expand the paradigm of the question you've been asked. If you allow it to be pushed into a narrow arena you cheat yourself and you cheat everyone else, and you limit your role. Being an engineer isn't just about solving discrete problems; it's about answering problems in unconventional ways. That's the kind of creative work people want engineers to do. There's always an opportunity to do it."