PERSPECTIVES

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The True Grand Challenge for Engineering: Self-Knowledge

In 2003, the National Academy of Engineering (NAE) published *A Century of Innovation* celebrating "20 engineering achievements that transformed our lives" across the 20th century, from automobiles to the Internet. Five years later, it followed up with 14 Grand Challenges for engineering in the 21st century, including making solar energy affordable, providing energy from fusion, securing cyberspace, and enhancing virtual reality. But only the most cursory mention was made of the greatest challenge of all: cultivating deeper and more critical thinking, among engineers and nonengineers alike, about the ways engineering is transforming how and why we live.

What Percy Bysshe Shelley said about poets two centuries ago applies even more to engineers today: They are the unacknowledged legislators of the world. By designing and constructing new structures, processes, and products, they are influencing how we live as much as any laws enacted by politicians. Would we ever think it appropriate for legislators to pass laws that could transform our lives without critically reflecting on and assessing those laws? Yet neither engineers nor politicians deliberate seriously on the role of engineering in transforming our world. Instead, they limit themselves to celebratory clichés about economic benefit, national defense, and innovation.

Where might we begin to promote more critical reflection in our engineered lives? One natural site would be engineering education. In this respect, it is again revealing to note the role of the NAE Grand Challenges. Not just in the United States, but globally as well, the technical community is concerned about the image of engineering in the public sphere and its limited attractiveness to students. The 2010 United Nations Educational, Scientific and Cultural Organization study *Engineering: Issues, Challenges and Opportunities for Development* lamented that despite a "growing need for multi-talented engineers, the interest in engineering among young people is waning in so many countries." The Grand Challenges have thus been deployed in the Grand Challenges Scholars Program as a way to attract more students to the innovative life. But to adapt the title of Vannevar Bush's *Science Is Not Enough*, a cultivated enthusiasm for engineering is insufficient. More pointedly, to paraphrase Socrates, "The unexamined engineering life is not worth living."

More than once in dialogue with Greek fellow citizens who boasted of their prowess in meeting challenges, Socrates referenced the words inscribed on the Temple of Apollo at Delphi: Know thyself. It is a motto that engineers—and all of us whose lives are informed by engineering—could well apply to ourselves.

An axial age

In a critical reflection on world history, the German philosopher Karl Jaspers observed how in the first millennium BCE, human cultures in Asia and Europe independently underwent a profound transformation that he named the Axial Age. Thinkers as diverse as Confucius, Laozi, Buddha, Socrates, and the Hebrew prophets began to ask what it means to be human. Humans no longer simply accepted whatever ways of life they were born into; they began to subject their cultures to critical assessment. Today we are entering a new Axial Age, one in which we no longer simply accept the physical world into which we are born. But engineering makes almost no effort to give engineers—or any of the rest of us—the tools to reflect on themselves and their world-transforming enterprise.

Engineering programs like to promote innovation in product creation, and to some extent in pedagogy, yet almost never in critical thinking about what it means to be an engineer. Surely the time has come for engineering schools to become more than glorified trade schools whose graduates can make more money than the hapless English majors whom Garrison Keillor lampoons on *A Prairie Home Companion*. How about engineers who can think holistically and critically about their own role in making our world and assist their nonengineering fellow citizens as well in thinking that goes beyond superficial promotions of the new? And where might engineers acquire some tools with which to cultivate such abilities? One place to start would be through engagement with the traditions of thought and critical self-reflection that emerged from the original Axial Age: what we now call the humanities.

Two cultures recidivus

To mention engineering and the humanities in the same sentence immediately calls to mind C. P. Snow's famous criticism of those "natural Luddites" who do not have the foggiest notion about such technical basics as the second law of thermodynamics. Do historians, literary scholars, and philosophers really know anything that can benefit engineers?

Snow's "two cultures" argument, as well as many discussions since, conflates science and engineering. The powers often attributed to science, such as the ability to overcome poverty through increased production of goods and to send people to the Moon by spaceship construction, belong more to engineering. As a result, there are actually two two-culture issues. The tension between two forms of knowledge production (sciences and the humanities) is arguably less significant than another between designing and constructing the world versus reflecting on what it means (engineering and the humanities).

Indeed, although there is certainly room for improvement on the humanities side, I venture that a majority of humanities teachers in engineering schools today could pass the test Snow proposed to the literary intellectuals he skewered. Yet in my experience relatively few engineers, when invited to reflect on their professions, can do much more than echo libertarian appeals to the need for unfettered innovation to fuel endless growth. Even the more sophisticated commentators on engineering such as Samuel Florman (*The Existential Pleasures of Engineering*), Henry Petroski (*To Engineer Is Human*), and Billy Vaughn Koen (*Discussion of the Method: Conducting the Engineer's Approach to Problem Solving*) are largely absent from engineering curricula.

The two-cultures problem in engineering schools is distinctive. It concerns how to infuse into engineering curricula the progressive humanities and qualitative social sciences, as pursued by literary intellectuals who strive to make common cause with that minority of engineers who are themselves critical of the cultural captivity of techno-education. There are, for instance, increasing efforts to develop programs in humanitarian engineering, service learning, and social justice. Nevertheless, having taught in three engineering schools, I—like many humanities scholars who teach engineering students—experience a continuing tension between engineering and the humanities. Such is especially the case today, in an increasingly corporatized environment at an institution oriented toward the efficient throughput of students who can serve as handmaids of an expanding energy industry.

On the one side, engineering faculty (administrators even more so) have a tendency to look on humanities courses as justified only insofar as they provide communication skills. They want to know the cash value of humanities courses for professional success. The engineering curriculum is so full that they feel compelled to limit humanities and social science requirements, commonly to little more than a semester's worth, spread over an eight-semester degree program crammed with science and engineering.

Unlike professional degrees in medicine or law, which typically require a bachelor's degree of some sort before professional focus, entry into engineering is via the B.S. degree alone. This has undoubtedly been one feature attracting many students who are the first members of their families to attend college. It is an upward-mobility degree, even if there is not quite the demand for engineers that the engineering community often proclaims.

Why humanities?

On the other side, humanities faculty (there are seldom humanities administrators with any influence in engineering schools) struggle to justify their courses. These justifications are of three unequal types, taking an instrumental, enhanced instrumental, and intrinsic-value approach.

The first, default appeal is to the instrumental value of communication skills. Engineers who cannot write or otherwise communicate their work are at a disadvantage, not only in abilities to garner respect from people outside the engineering community but even within technical work teams. The humanities role in teaching critical thinking is an expanded version of this appeal. All engineers need to be critical thinkers when analyzing and proposing design solutions to technical problems. But why no critical thinking about the continuous push for innovation itself? Too often, the humanities are simply marshalled to provide rhetorical skills for jumping aboard the more-is-better innovation bandwagon—or criticized for failing to do so.

A second, enhanced instrumental appeal stresses how humanities knowledge, broadly construed to include the qualitative social sciences, can help engineers manage alleged irrational resistance to technological innovation from the nonengineering world. This enhanced instrumental appeal argues that courses in history, political science, sociology, anthropology, psychology, and geography—perhaps even in literature, philosophy, and religion—can locate engineering work in its broader social context. Increasingly engineers recognize that their work takes place in diverse sociocultural situations that need to be negotiated if engineering projects are to succeed.

In similar ways, engineering practice can itself be conceived as a techno-culture all its own. The interdisciplinary field of science, technology, and society (STS) studies receives special recognition here. Many interdisciplinary STS programs arose inside engineering schools, and even after their transformation to disciplinary science and technology studies, some departments have remained closely connected to engineering faculties.

The enhanced instrumental appeal further satisfies ABET (the new acronym name for what used to be the Accreditation Board for Engineering and Technology) requirements. In order to be ABET-accredited, engineering programs must be structured around 11 student outcomes. Central to these outcomes are appropriate mastery of technical knowledge in mathematics and the sciences, including the engineering sciences, and the practices of engineering design, including abilities "to identify, formulate, and solve engineering problems" and "to function on multidisciplinary teams." Engineers further need to learn how to design products, processes, and systems "to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" and possess "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context." Finally, engineering students should be taught "an ability to communicate effectively" and "professional and ethical responsibility." Clearly the humanities need to be enrolled in the process of delivering the more fuzzy of these outcomes.

The challenge of professional ethical responsibility deserves highlighting. It is remarkable how, although professional engineering codes of ethics identify the promotion of public safety, health, and welfare as primary obligations, the engineering curriculum shortchanges these key concepts. There exists a field termed safety engineering but none called health or welfare engineering. And even if there were, because the promotion of these values is an obligation for all engineers, their examination would need to be infused across the curriculum. Physicians, who also have a professional commitment to the promotion of health, have to deal with the meaning of this concept in virtually every course they take in medical school.

The 2004 NAE report on *The Engineer of 2020: Visions of Engineering in the New Century* emphasized that engineering education needs to cultivate not just analytic stills and technical creativity but communication skills, management leadership, and ethical professionalism. Meeting almost any of the subsequent NAE list of Grand Challenges, many engineers admit, will require extensive social context knowledge from the humanities and social sciences. The humanities are accepted as providing legitimate if subordinate service to engineering professionalism even as they are regularly shortchanged in engineering schools.

But it is a third, less instrumental justification for the humanities in engineering education that will be most important for successfully engaging the ultimate Grand Challenge of self-knowledge, that is, of thinking reflectively and critically about the kind of world we wish to design, construct, and inhabit in and through our technologies. The existential pleasures of engineering, not to mention its economic benefits, are limited. Human beings are not only geeks and consumers. They are also poets, artists, religious believers, citizens, friends, and lovers in various degrees all at the same time. The engineering curriculum should be more than an intensified vocational program that assumes students either are, or should become, one-dimensional in their lives. Engineers, like all of us, should be able to think about what it means to be human. Indeed, critical reflection on the meaning of life in a progressively engineered world is a new form of humanism appropriate to our time—a humanities activity in which engineers could lead the way.

Re-envisioning engineering

Primarily aware of requirements for graduation, engineering students are seldom allowed or encouraged to pursue in any depth the kind of humanities that could assist them, and all of us, in thinking about the relationship between engineering and the good life. They sign up for humanities classes on the basis of what fits their schedules, but then sometimes discover classes that not only provide relief from the forced march of technical work but that broaden their sense of themselves and stimulate reflection on what they really want to do with their lives. A few months ago a student in an introduction to philosophy class told me he was tired of engineering physics courses that always had to solve practical problems. He wanted to think about the nature of reality.

If he drops out of engineering, as some of my students have done, the humanities are likely to be blamed, rather than credited with expanding a sense of the world and life. The cost/benefit assessment model in colleges today is progressively coarsening the purpose of higher education. As Clark University psychologist Jeffrey Arnett argues, emerging adulthood is a period of self-discovery during which students can explore different paths in love and work. It took me seven years and three universities to earn my own B.A., years that were in no way cost/benefit-negative. Bernie Machen, president of the University of Florida, has been quoted (in the *Chronicle of Higher Education*) as telling students that their "time in college remains the single-best opportunity … to explore who you are and your purpose in life." Engineering programs, because of their rigorous technical requirements, tend to be the worst offenders at cutting intellectual exploration short. This situation needs to be reversed, in the service of both engineering education and of our engineered world. If they really practiced what they preached about innovation, engineering schools would lead the way with expanded curricula and even B.A. degrees in engineering.

In physicist Mark Levinson's insightful documentary film *Particle Fever*, the divide between experimentalists and theorists mirrors that between engineering and the humanities. But in the case of the Large Hadron Collider search for the Higgs' boson chronicled in the film, the experimentalists and theorists work together, insofar as theorists provide the guidance for experimentation. Ultimately, something similar has to be the case for engineering. Engineering does not provide its own justification for transforming the world, except at the unthinking bottom-line level, or much guidance for what kind of world we should design and construct. We wouldn't think of allowing our legislators to make laws without our involvement and consent; why are we so complacent about the arguably much more powerful process of technical legislation?

As mentioned, what Jaspers in the mid-20th century identified as an Axial Age in human history—one in which humans began to think about what it means to be human—exists today in a new form: thinking about what it means to live in an engineered world. In this second Axial Age, we are beginning to think about not just the human condition but what has aptly been called the techno-human condition: our responsibility for a world, including ourselves, in which the boundaries dissolve between the natural and the artificial, between the human and the technological. And just as a feature of the original Axial Age was learning to affirm limits to human action—not to murder, not to steal—so we can expect to learn not simply to affirm engineering prowess but to limit and steer our technological actions.

Amid the Grand Challenges articulated by the NAE there must thus be another: The challenge of thinking about what we are doing as we turn the world into an artifact and the appropriate limitations of this engineering power. Such reflection need not be feared; it would add to the nobility of engineering in ways that little else could. It is also an innovation within engineering in which others are leading the way. The Netherlands, for instance (not surprisingly, as the country that, given its dependence on the *Deltawerken*, comes closest to being an engineered artifact), has the strongest community of philosophers of engineering and technology in the world, based largely at the three technological universities of Delft, Eindhoven, and Twente and associated with the 3TU Centre for Ethics and Technology. China, which is undergoing the most rapid engineering transformation in world history, is also a pioneer in this field. The recent 20th-anniversary celebration of the Chinese Academy of Engineering included extended sessions on the philosophy of engineering and technology. Is it not time for the leaders of the engineering community in the United States, instead of fear-mongering about the production of engineers in China, to learn from China—and to insist on a deepening of our own reflections? The NAE Center for Engineering, Ethics, and Society is a commendable start, but one too little appreciated in the U.S. engineering education world, and its mandate deserves broadening and deepening beyond ethical and social issues.

The true Grand Challenge of engineering is not simply to transform the world. It is to do so with critical reflection on what it means to be an engineer. In the words of the great Spanish philosopher José Ortega y Gasset, in the first philosophical meditation on technology, to be an engineer and only an engineer is to be potentially everything and actually nothing. Our increasing engineering prowess calls upon us all, engineers and non-engineers alike, to reflect more deeply about who we are and what we really want to become.

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