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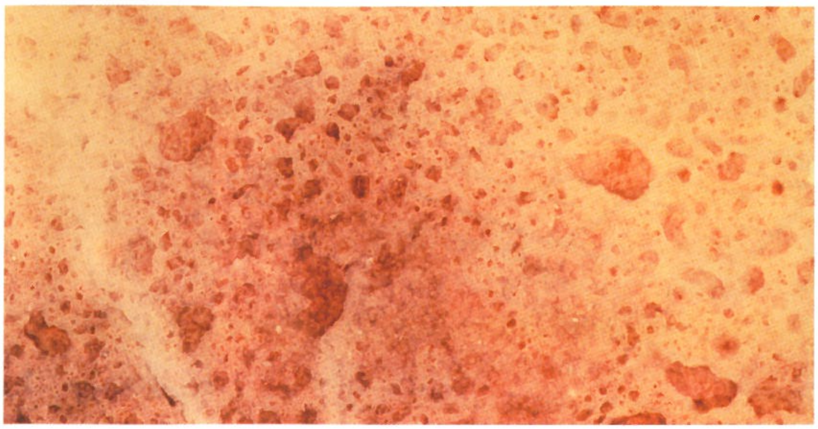


Ajay Malghan, *McDonalds Hamburger Bun.*

these previously inaccessible reserves.

In the past decade, while U.S. shale gas production grew 10-fold, conventional natural gas production dropped 37%. Conventionals accounted for 16% of the nation's natural gas production in 2012; by 2040, that share will shrink to 4%. This won't be by choice. Conventional reserves are shrinking; in short, we've recovered all the easy stuff. Future fossil fuel extraction will take us deeper underground and below the ocean floor, to more remote corners of the globe, and into less permeable formations.

Whereas the focus of the "fracking debate" has centered on what's different about unconventional production, the bigger story may be how little techniques have changed in these new, tougher extraction environments. Despite advances in directional drilling and cement chemistry, as well as impressive developments in other pertinent areas, the basic steps for well construction and production are much as they were decades ago. When applied to unconventional development, these steps demand more energy and industrial inputs. Researchers at Argonne National Laboratory have found that Marcellus shale gas wells require three times more steel, twice as much cement, and up to 47 times more water than a conventional natural gas well. The greater scale and intensity of unconventional development may be the key driver of risk to public health, the environment, and community character.

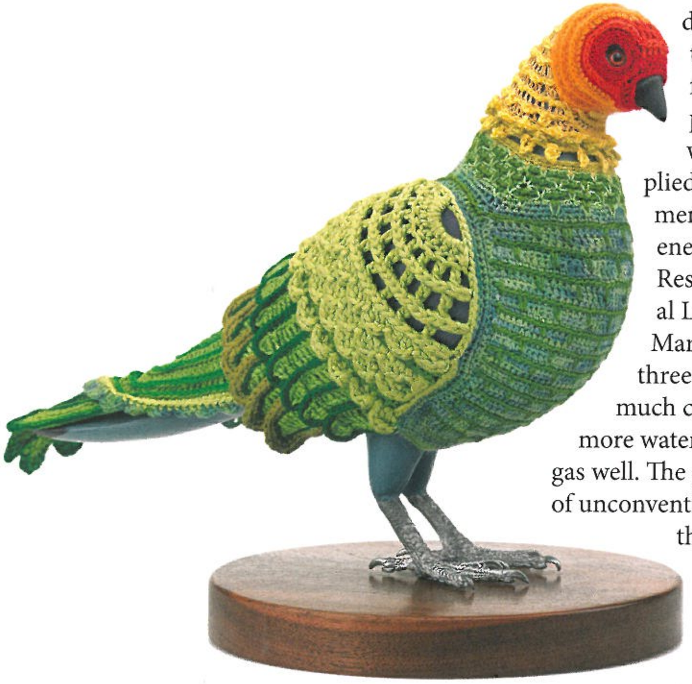
The authors are exactly right that the way to identify and respond to this risk is through data collection, scientific research, and public disclosure. The question is how to advance in this effort. The situation is somewhat more complex than the article implies, and thus it may be more hopeful than warranted for several reasons.

First, the article posits that "concerted actions by industry severely limit regulation and disclosure." However, this sector is incredibly diverse, comprised of hundreds if not thousands of companies ranging from mom-and-pop shops to Fortune 500 companies. The industry can't even agree on a single trade group to represent its interests. The multiplicity of diverse actors poses a serious governance challenge but also affords an opportunity to find support for risk-based regulation. Companies may find that a greener position on regulation could win them social license, price premiums, or contracts with distribution companies sensitive to consumer environmental concerns.

Second, the article advocates federal regulation of unconventional oil and gas production. Under current law, federal agencies could regulate more aspects and outcomes of this activity. (Despite the exemptions noted, federal authority exists or could be triggered by agency action in each environmental statute listed.) However, in the past five years we've seen a more robust regulatory response from states. State agencies house much of the nation's oil and gas regulatory expertise, and at least in some cases they boast strong sunshine and public participation laws (while sometimes exempting oil and gas).

Federal regulation is not a yes or no question. It can be used to lead, nudge, complement, or supplant state action, depending on the issue and the context. In data collection and research, federal agencies could set harmonized data collection standards, compile and share risk data, and fund research to change how we extract unconventionals and how we reduce our dependence on these fossil fuels.

Kate Konschnik
Director, Environmental Policy Initiative
Harvard Law School



Laurel Roth Hope

Biodiversity Reclamation Suit: Carolina Parakeet, 2009

Suit: cotton, silk, bamboo, wool, and acrylic blended yarn; mannequin: basswood, acrylic paint, gouache, glass, pewter, and walnut

Smithsonian American Art Museum, gift of Joyce Schwartz in honor of Judith S. Weisman, museum purchase from friends of the Renwick Gallery. © 2009, Laurel Roth Hope.

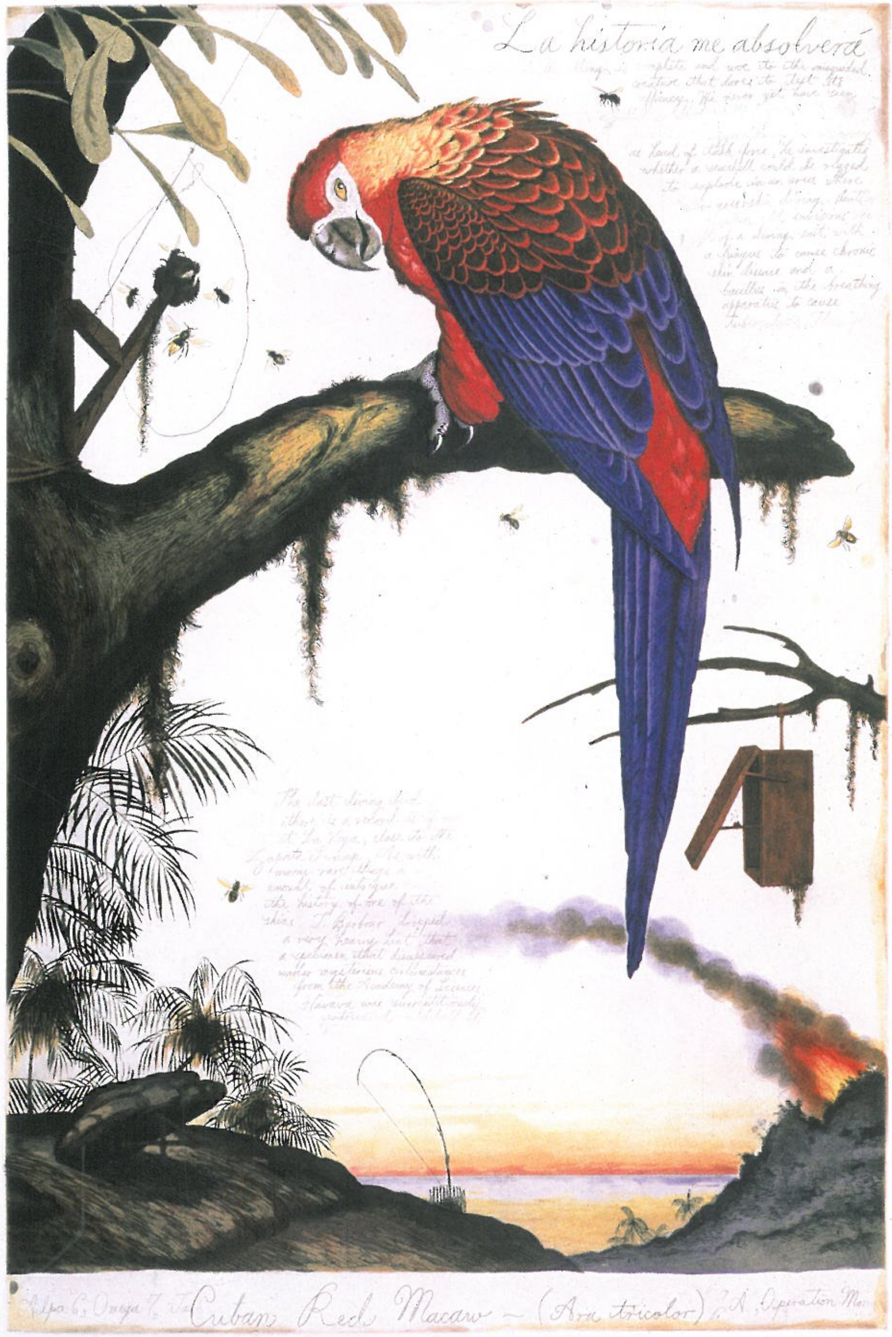
Grand challenge for engineers

The National Academy of Engineering's Grand Challenges for Engineering posits a list of far-reaching technical problems that, if solved, will have a momentous impact on humanity's future prosperity. In "The True Grand Challenge for Engineering: Self-Knowledge" (*Issues*, Fall 2014), Carl Mitcham proposes an additional challenge of educating engineers capable not only of attacking the technical challenges, but also of tackling the questions presupposed by the list: What does a prosperous human future entail? What kind of world should we strive for? What role should the engineer play in achieving such ends?

Mitcham argues that engineers need to learn to think critically about what it means to be human and calls for engineering education to embrace the humanities for their intrinsic value (rather than as a service provider for communications skills). So how grand a challenge is the author's proposal? I believe there is good reason for pessimism, but also for optimism.

I'm pessimistic when I take a high-level view. Much has been written about the contemporary trend in higher education toward commoditization, with its economically instrumental view of academic programs, and even the specter of institutions outsourcing the humanities to online providers. None of that augurs well for a more reflective education for anyone, much less engineers. As for engineering, radically reformulating engineering education in any overarching way has proved difficult. For example, some years ago, the American Society of Civil Engineers gamely advocated for a master's degree as the first professional degree, in part to produce "more broadly trained engineers with an education that more closely parallels the liberal arts experience." The society subsequently softened its stance due to inertia in the system, and a mandated liberal arts-like experience for engineers has certainly not materialized.

Yet, I'm optimistic when I take a grassroots view. Consider this recent Forbes headline: "Millennials Work for Purpose, Not Paycheck." Seemingly against the instrumental trajectory of higher education, the current college generation appears to place a premium on meaningful work that contributes to the well-being of global society, sug-



Walton Ford

La Historia Me Absolvera, 1999

Color etching, aquatint, spit-bite and drypoint on paper

Artwork and image courtesy of the artist and Paul Kasmin Gallery.

Paula McCartney

Winter Bluebirds (top), 2005

Vermilion Flycatchers (bottom), 2006

Chromogenic prints

Smithsonian American Art Museum, museum purchase through the Luisita L. and Franz H. Denghausen Endowment. © 2010, Paula McCartney.

gesting a potential market for the type of education Mitcham champions. And if the educational system isn't responsive to that demand from the top down, perhaps it can be from the bottom up. For example, Mitcham mentions humanitarian engineering programs, which his institution helped pioneer and which are increasingly popping up at schools across the United States, including my own.

Similarly, new programs in sustainable engineering or sustainable development engineering have recently arisen on many campuses. These types of programs didn't exist just a few years ago. They have developed organically, rather than in response to any broad policy, and they tend to value engineers learning about the human condition. Another recent phenomenon has been the rise of 3-2 duel engineering programs involving liberal arts colleges, with students earning both B.A. and B.S. degrees. Granted, such paths still represent a small slice of the engineering education pie, but I'm hopeful they will grow and spread, perhaps nucleating Mitcham's desired change from the inside out.

Byron Newberry
Professor of Mechanical Engineering
Baylor University

There is reason to believe that Carl Mitcham's goal can be achieved. With the adoption by ABET (a nonprofit, nongovernmental organization that accredits college and university programs in the disciplines of applied science, computing, engineering, and engineering technology) of Engineering Criteria 2000, engineers are expected to develop personal and professional responsibility and understand the broader effects of engineering projects, which provides a solid departure point for seeking "self-knowledge." And although several emerging obstacles may prevent the chasm between the two cultures of the humanities and engineering from being easily bridged, they may also reveal creative opportunities.

The first obstacle is fragmentation of the university. Institutional separation of colleges and departments, necessary for many reasons, is made materially manifest in the creation of science and research parks formed in collaboration with commercial entities. Given the steep decline in public funding, private funding for research may seem like pure good fortune. Yet creation of such parks may introduce physical barriers that can prevent interdisciplinary work and collegiality among faculty and students in engineering and those in the humanities. Moreover, the proprietary nature of much research done in such collaborations is contrary to the goal of democratizing knowledge, an important justification for the public funding universities still receive.

The second obstacle is the exponential growth of technical knowledge that must be mastered to do engineering work. The "Raise the Bar" initiative, supported by the National Society of Professional Engineers and the National Council of Examiners for Engineering and Surveying, has responded to the increased demands on engineers by changing professional licensure to require either a master's degree or equivalent in the near future. Andrew W. Herrmann, past president of the American Society of Civil Engineers, characterized the changes as similar to what other "learned professions" had done to cope with increasing demands on their members and as a move that would raise the stature of the engineering profession.

Although an initial response may be to assign additional educational requirements to technical courses, more innovative departments should consider repositioning an engineering education to generate as many opportunities as possible for its students to interact with the humanities and social sciences. To

Joann Brennan

Peregrine Falcon. Denver Museum of Nature and Science, Zoology Department (over 900 specimens in the collection), Denver, Colorado, 2006

Chromogenic print

Artwork and image courtesy of the artist, Denver, Colorado. © 2006, Joann Brennan.

do this will require financial support for engineering students who are interested in earning minors (or even second majors) in those areas, perhaps by devoting a small share of the resources dedicated to collaborative private/public research projects to this end. Such support may attract interest from underrepresented groups by showing that engineering education means development of the whole person, not just their technical skills. It would also provide tangible proof to the public that its financial support is more than subsidized job training for favored industries, while also demonstrating to ABET that an engineering department is committed to excellence for all learning outcomes, not just those related to engineering sciences.

Repositioning engineering education should also provide an opportunity for engineering departments to do their part in bridging the two-culture divide by promoting minors in engineering disciplines to humanities and social sciences majors. In a world in which technology is ubiquitous, increasing the quality and quantity of public knowledge about engineering should increase the quality of public discourse on technological projects.

Glen Miller
Department of Philosophy
Texas A&M University

I applaud Carl Mitcham's call to recognize engineering education as one of the Grand Challenges for engineering in the 21st century. Engineers will continue to play a pivotal role in solving the enormous problems facing the world, but the education at most engineering schools is not preparing their students for the sociotechnical complexity or the global scale of the problems. The narrowness of engineering education has long been recognized, and although a few institutions have made serious efforts to change, engineering education remains narrow. The curriculum provides few opportunities for students to develop substantive nontechnical perspectives; few opportunities to see engineering in the broad social and political context in which it operates and has consequences; and few opportunities to develop the personal attributes and understanding that might lead to more socially responsive and responsible solutions.

Engineers are, in Mitcham's words, "the unacknowledged legislators of the world" insofar as they create technologies that order and regulate how we live. Of course, engineers are not alone in doing this. The organizations that employ them, regulatory agencies, markets, and media all have a role. If engineers are to play an effective role, they must understand their relationships with these other actors and they must understand the broader context of their work (not just the workplace). In short, they must understand engineering as a sociotechnical enterprise.

Engineering education is appropriately a Grand Challenge because it is not a small or easy problem. A dose of humanities—a few required humanities and social science courses—won't do the job. In part, this is because many of the humanities and social sciences don't address the technological character of the world we live in. They may allow students to consider the meaning of life, but without acknowledging the powerful role technology plays shaping our lives. So the Grand Challenge involves changing humanities and social science education as well as engineering education.

The Grand Challenge has another component that is rarely recognized. Understanding how technology and society are intertwined is not just important for engineers. Non-engineers need to understand how technology regulates everyone's lives. Thus, part of the challenge of engineering education is to figure out what citizens need to know about technology and engineering. Again, it is not a small or easy problem. Citizens can't become experts in engineering, so we need to figure out what kinds of information and skills they do need. Most colleges and universities require liberal arts students simply to take a certain number of science courses. This is woefully inadequate to prepare students for living in this science- and technology-dependent world.

In my own experience, bringing insights, theories, and concepts from the field of science, technology, and society studies has been enormously helpful in engaging engineering students in thinking more broadly about the implications of their work and seeing ways to design things that solve broader problems. For example, focusing on how Facebook and Google algorithms determine the information that users see, and the significance of this for democracy, may change the way engineering students think about writing computer code. Similarly, focusing on the politics of decisions about where to site bridges frames engineering as implicitly a sociotechnical enterprise. Notice that this approach might work as well for liberal arts students. Indeed, it might stimulate them to enroll in science and engineering fields.

Deborah G. Johnson
Anne Shirley Carter Olsson Professor of Applied Ethics Science
University of Virginia

Carl Mitcham proposes that because engineering fundamentally transforms the human condition, engineering schools have a duty to educate students who will be able to think reflectively and critically on the transformed world that they will help create. What should students learn and then reflect on as they move through their professional careers? Mitcham refers to the National Academy of Engineering's Greatest Engineering Achievements of the 20th Century and Grand Challenges for Engineering as being insufficient in how they critically explore the achievements and challenges that have or will transform the world. Perhaps the National Academies should develop a follow-on project, Engineering: Transforming the Human Condition and Civilization.

The project could serve as source for curriculum across engineering education as well as for other fields and for continuing education. The overarching

Tom Uttech

Enassamishhinjijweian, 2009

Oil on linen

Crystal Bridges Museum of American Art, Bentonville, Arkansas. Courtesy of Alexandre Gallery, New York. Photo by Steven Watson. ©Tom Uttech.

theme would be not only the triumphs, but also the tragedies in the transformation of civilization from the hunter-gatherer societies symbolized in cave paintings of over 30,000 years ago, to agrarian societies, to industrialization, and now to a techno-info-scientific society.

The challenge is to organize our knowledge so that the big picture—the fantastic story of human civilization; who we are and what we are becoming as beings on this watery planet—is coherent and accessible. One strategy would be to organize the knowledge as the evolution of technological systems and the increasing interactions of such systems. One thread through time is the nexus of food, water, and energy. One can learn how these systems changed over time, including the connections with transportation, materials, and the built environment, for example. From the moldboard plow pulled with horses planting open-pollinated crops to autonomous self-driving tractors and genetically engineered crops that are robotically harvested, how is one system better than the other—or is it? Then there is the issue of our increasing reliance on space systems for weather and climate information, and perhaps for attempting to engineer the climate in a way we desire.

These systems are not just technical, but sociotechnical, reflecting the interests, values, costs and benefits, winners and losers in the distribution of benefits and costs, the power to influence what happens, and the adjudication in some cases of what systems become realized in the world. It is messy. These are the details that matter and influence the evolution of sociotechnical systems and who we become.

Darryl Farber
Assistant professor of Science, Technology, and Society
Penn State University

Addressing the Grand Challenge formulated by Carl Mitcham, when done well, could lead to revolutionary changes in the way society innovates. But who will initiate and execute self-reflection among engineers? Within universities, three groups can be identified: the administration, technical faculty, and liberal arts faculty. Change is most effective when it is driven both top-down and bottom-up, which means the involvement of administration and faculty.

But in reality, the administration is often loath to take on this role, in part because of financial reasons. Technical faculty are often wrapped up in their research and teaching, and as a result may not pay much attention to the broader impact of their work. That leaves the liberal arts faculty. But since at technical universities this group is often seen as providers of service courses, they alone may not have the clout to realize institution-wide change. So again the question: who will be the agent of change?

What is needed is a movement among faculty, students, and, preferably, individuals in the administration. This movement will be most effective when it includes technical faculty who are seen as role models. Inclusion of liberal arts faculty is essential because of their societal insight and critical thinking skills. Because of their complementary expertise, technical faculty and liberal arts faculty may need to educate each other. Faculty organizations, such as a faculty senate, research council, research centers, or individual departments, could play a key role. Other initiatives, such as reading groups, high-profile speakers, and thought-provoking contributions to campus publications, may also contribute.

Funding agencies also have an opportunity to be agents of change. The National Science Foundation (NSF), for example, requires that the students and postdoctoral fellows it funds receive ethics training. Requiring that grant applicants address the Grand Challenge outlined by Mitcham would naturally fit under the Broader Impact criterion used by the NSF.

So members of the campus communities, stand up—and in the words of Gandhi, "be the change you want to see in the world!"

Roel Snieder
W.M. Keck Distinguished Professor of Basic Exploration Science
Colorado School of Mines

I cannot but wholeheartedly subscribe to Carl Mitcham's wake-up call to all of us, but to engineers in particular, to face 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." Critical thinking is the pivotal notion of his wake-up call. But what are the tools of critical thinking, and where are engineers to turn for support in developing and applying these tools? Mitcham advises engineers to turn to the humanities.

But are the humanities up to this task? What kinds of tools for critical thinking have they to offer, and are they appropriate for the problems we are facing in our technological age? Take philosophy. In the 20th century, philosophy has developed into a discipline of its own, with philosophers writing mainly for philosophers. There is no shortage of critical thinking going on in philosophy, but is it the kind of critical thinking that engineers need? I have serious doubts, given that reflection on science and technology plays only a marginal role in philosophy.

What is true of philosophy is also true, I fear, for many of the other humanities. Here lies a grand challenge for the humanities: to turn their analytical and critical powers to the single most characteristic feature of the modern human condition, technology, and to engage in a fruitful dialogue with engineers, who play a crucial role in developing this technology. If they face up to this challenge, they may be the appropriate place for engineers to turn for guidance in dealing with their quest for self-knowledge.

Peter Kroes
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Delft University of Technology
The Netherlands