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ARTICLE: GUEST INTRODUCTION TO SPECIAL ISSUE

Great Problems of Grand Challenges: Problematizing Engineering’s Understandings of Its Role in Society

Erin Cech

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The U.S. National Academy of Engineering’s Grand Challenges for Engineering report has received a great deal of attention from legislators, policymakers, and educators, but what does it entail for social justice considerations in engineering? This article situates the Grand Challenges report as a cultural artifact of the engineering profession—an artifact that works to reinforce engineering’s professional culture, recruit new members, and reassert engineering’s legitimacy in the 21st century. As such, the Grand Challenges report provides a unique opportunity to understand and critique the role engineering envisions for itself in society. The articles in this special issue of IJESJP identify four central critiques of Grand Challenges: authorial particularism, double standards in engineering’s contributions to these challenges, bracketing of the “social” from “technical” realms, and deterministic definitions of progress. These critiques call for increased reflexivity and broadened participation in how engineers define problems and attempt to solve them.

KEYWORDS: Grand Challenges, National Academy of Engineering, participation, reflexivity, technical-social division

INTRODUCTION

Throughout human history, engineering has driven the advance of civilization. From the metallurgists who ended the Stone Age to the shipbuilders who united the world’s peoples through travel and trade, the past witnessed many marvels of engineering prowess. . . . In the century just ended, engineering recorded its grandest accomplishments. The widespread development and distribution of electricity and clean water, automobiles and airplanes, radio and television, spacecraft and lasers, antibiotics and medical imaging, and computers and the internet [sic] are just some of the highlights of a century in which engineering revolutionized and improved virtually every aspect of human life. (National Academy of Engineering, 2008, p. 1–2)

With a statement like this, it is hard to imagine how any other profession or realm of expertise might have contributed to societal change in the last two millennia. It is also hard to recognize that the engineering profession, as a legitimated entity separate from the work of artisans, craftspeople, and scientists, has only existed since the mid-19th century (Hughes, 2005). These epically-worded sentiments are just a few of many included in the introduction to the Grand Challenges of Engineering, a 50-page report produced by the National Academy of Engineering to document important challenges facing “civilization’s continuing advancement” and the role of engineering in solving those challenges. More than simply a “to-do” list of priorities envisioned by leading engineers, this report is an important moment when the profession makes clear and bold statements about its role in society. But, in this moment, which has commanded the attention of
legislators, policy makers, educators, and current and future engineers, the Grand Challenges makes scarce reference to the ethical justification for the pursuits it proposes. It also sidesteps the ramifications of these pursuits for social justice. By defining engineering responsibilities (and, indeed, human progress itself) as narrowly technological, the Grand Challenges closes off space for considering the professions’ responsibilities (or past and present contributions) to social (in)justice in the United States and abroad.

The authors of the articles in this special issue use the Grand Challenges as an opportunity to critically examine engineering’s self-presentation and to ask important questions about how the profession’s role in society might be envisioned differently. To set the stage, the present article frames the Grand Challenges as an historical and cultural artifact and explains why it is deserving of investigation. I discuss what the report means in the broader context of a profession acting to secure its legitimacy and power in society. I then describe the four central critiques that emerge from the articles in this issue and end by discussing what each of these critiques call for: greater reflexivity and broader participation in the search for engineering problem definitions and solutions.

The Grand Challenges report is a product of the United States’ National Academy of Engineering (NAE), arguably the most prestigious organization within the engineering profession in the U.S. Engineers elected to be fellows of NAE are understood to be leaders in their subfields in industry and academia and are often called upon to advise technology and education-related policymaking. A panel of eighteen professionals, all in science and engineering fields, and most with primary ties to the United States (Riley, this issue), was charged by the U.S. National Science Foundation with crafting the report. The Grand Challenges authors selected fourteen challenges they understood to be achievable (as well as sustainable) that would “help the people and the planet thrive” (p. i). (See Table 1 for a list of the fourteen challenges.) The Grand Challenges website offers a place for the general public to submit comments on the challenges (www.engineeringchallenges.org), although it is unclear how, if at all, these comments affect the subsequent web content surrounding the report.

In addition to the report itself, the Grand Challenges website offers a 6-minute high-quality video narrated by panel members, a “K–12 Partners Program” with lesson plans and pedagogical suggestions, a “Grand Challenges Scholars Program,” and an annual poster contest. As several of the articles in this issue discuss, the report has circulated widely among engineering educators, lawmakers, and industry leaders.

The influence of this report alone, as an enticement for future engineers and reminder of engineering’s greatness for the converted, makes it an important site for investigation. However, Grand Challenges is more than an advertisement of engineering’s power and prominence. This report is a cultural artifact representing the profession’s statement of its role in society. As such, it serves several purposes for the engineering profession. First and foremost, Grand Challenges is a claim for the

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<td>Make solar energy economical</td>
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<td>Provide energy from fusion</td>
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<td>Develop carbon sequestration methods</td>
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<td>Manage the nitrogen cycle</td>
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<td>Provide access to clean water</td>
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<td>Restore and improve urban infrastructure</td>
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<td>Advance health informatics</td>
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<td>Engineer better medicines</td>
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<td>Reverse-engineer the brain</td>
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<td>Secure cyberspace</td>
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<td>Enhance virtual reality</td>
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<td>Advance personalized learning</td>
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legitimacy of the profession in 21st century societies. Such legitimacy is by no means guaranteed or perpetually conferred to established professions (Abbott, 1988). One could imagine several challenges to engineering's legitimacy: some people might say that engineering was once an important profession, but its current relevance to society is diminishing. Others might say that trends toward sustainability, simplicity, and reusability render engineering's grand visions of “high-tech” solutions no longer desirable. In the face of such real or imagined critiques, Grand Challenges presents a forceful argument (perhaps one resembling a politic of fear) that the engineering profession deserves to remain at the table among the most respected professions in the world.

Such claims to legitimacy are neither new nor unique to engineering (Hughes, 1975, 2005; Nye, 1992. Amy Slaton's article in this issue chronicles the history of similar claims of engineering's legitimacy, dating back to its beginnings as a profession. Indeed, the establishment of legitimacy is the central feature of professionalization, the process by which a collection of jobs, skills and knowledge carve out a social and cultural space separate from other professions, secures a monopoly over those jobs, skills, and knowledge, and gains recognition for itself as a profession (Freidson, 1973; Gorman & Sandefur, 2011). However, a profession's fight for legitimacy is not over once it has established legal recognition and credentialing procedures; professions must continually reassert their relevance in a changing society and protect their jurisdiction of practice and expertise from encroachment by other professions (Abbott, 1988). The Grand Challenges report represents a relatively rare example of a profession explicitly communicating its relevance and patrolling its own jurisdictional boundaries.

Second, Grand Challenges is simultaneously a celebration and a reinforcement of engineering's professional culture. As the socio-cultural glue that unites the various tasks and jobs into a single “social collective” (Grusky, 2005; Weeden & Grusky, 2005), the professional culture of engineering encompasses the rich myths, rituals, and meaning systems that give engineering its particular flavor and delineate its values and priorities from other professions. This culture is reinforced through professional journals, conferences, and interactions between profession members, and is reproduced in new generations through professional socialization in engineering education (Becker et al., 1961; Schleef, 2006; Trice, 1993). But professions also require platforms to re-tell their tall tales and origin myths to a wider audience. The Grand Challenges report, particularly the sections of the introduction quoted above, aptly serves this purpose. It celebrates engineering’s (imagined) origins in some of the most consequential technical innovations of human history (fire, the wheel), claiming a direct lineage from those grand inventions to engineers of today and the work they envision for the future. This cultural history is certainly meant to inspire awe from those outside the profession, but the more probable effect is that it invokes pride among engineers, reminding profession members of their collective greatness.

More importantly, the Grand Challenges endeavor reinforces the values and norms most important to engineering culture. The report clearly emphasizes efficiency, economy, and large-scale and complex solutions over simpler “low-tech” solutions, and purely “technical” problem-solving over access and engagement with “social” or “political” elements (a critique discussed in more detail below). The beliefs and norms hidden between the lines of specific challenges and their solutions serve as reminders to engineers of what is valued most in past, present and future engineering work. The engineer-as-hero novels of the 1880s, which presented (men) engineers as cowboy-like figures who saved the nation through grandiose feats of engineering and always “got the girl” in the end (Nye, 1992) served a similar culture-reinforcing purpose over a century ago.

Finally, and more overtly, Grand Challenges is a recruitment tool for young people. As noted above, NAE developed spin-off materials to be used in K–12 education to entice students to join the ranks
of engineering so they, too, could “revolutionize” and “improve” virtually “every aspect of human
life” (p. 2). (The Marines’ well-phrased slogans, TV commercials, and video games are perhaps
the most visible examples of recruitment tools used by professions in the U.S.). This recruitment tool
may have been the impetus behind the U.S. National Science Foundation’s request that NAE create
the Grand Challenges report in the first place.

All professions engage in similar processes to secure their continued legitimacy, celebrate their
accomplishments, reinforce their professional culture, and recruit new members. But, compared to
other professions, engineering’s vision of its own social utility has historically been particularly vast
and encompassing (Hughes, 2005; Nye, 2006; Slaton, this issue).

Thus, the Grand Challenges report is an important cultural and historical site for understanding the
current state of the profession—the role it envisions for itself in the past and in the future, its tools
for recruiting the next generation of profession members, the values and norms most central to its
professional culture and, thus, its very approach to the work of problem definition and problem
solving. This lengthy treatise on the state of the profession through the profession’s own words
provides scholars with an opportunity to understand and critique the profession and to suggest
alternate courses of action.

Although the report is a useful vehicle for understanding the engineering profession, leveling
critiques at the Grand Challenges for Engineering comes with own challenges. The claims of
legitimacy embedded in this document means that questioning the Grand Challenges report may be
misunderstood as critiques of the very legitimacy of the engineering profession itself. After all, the
report represents that which is held most dear in the culture of engineering. However, critiques of
the Grand Challenges—especially those that can be extended to the profession itself—are not an
affront to the arguably beneficial work of much of the engineering profession in the past and
present, nor do they deny that many of the fourteen challenges are indeed important problems
facing 21st century societies (at least post-industrial ones). As Catalano (this issue) points out, the
authors critique the role that engineering sets out for itself in the present and future, not whether
engineering should have a role at all. As I describe in the next section, these critiques neither deny
the legitimacy of engineering as a profession, nor reject engineering expertise, but rather critique
the particular context out of which these challenges, and their proposed solutions, are defined. I
next describe the four central themes around which the authors in this issue offer their analysis of
the Grand Challenges for Engineering and discusses how these critiques lead to a deeper
understanding of engineering’s role in social justice.

THEMES OF CRITIQUE

While the authors in this issue approach the Grand Challenges from different theoretical
perspectives and employ different methodologies, several themes of critique emerge out of these
articles. Delineating these themes allows the articles to point collectively to the most troubling
aspects of engineering as they are manifested in the Grand Challenges report. I describe the four
themes below and then discuss the recommendation for change that underlies all these critiques:
the need for reflexivity and increased participation in engineering problem definition and solution.

Authorial Particularism

The first theme emerging out of several of the articles concerns the authorship of the Grand
Challenges. Who participated in selecting these challenges and recommending particular solutions
to them? Do the particular positions and interests of the committee members skew the
representativeness of the challenges and solutions themselves? Riley’s examination of the Grand
Challenges committee finds that all authors are either engineers or scientists, most of them work in corporate organizations or research institutions, and only three of the eighteen committee members are women (and only one of those women is an engineer). Nieusma and Tang echo Riley’s observation that many of the fourteen challenges and their proposed solutions are curiously particular to committee members’ own companies or research expertise. For example, fixing the nitrogen cycle and carbon sequestration—two very specific issues in the much broader problem of global climate change—are both domains of interest to one individual committee member (Riley, this issue). This particularism begs the question: would a more interdisciplinary and gender-balanced committee have arrived at a different set of challenges and proposed engineering solutions?

Perhaps more disconcerting, there is no evidence that the committee recognized this particularism; there is no acknowledgement that the makeup of the committee itself may have biased the types of challenges it found most pressing. This is reminiscent of the “god trick” identified by Donna Haraway (1988), whereby scientists and technologists presume (and are presumed to have) a “view from nowhere” from which they can define priorities and describe “reality.” Acknowledgement of the committee members’ own situatedness may have led to different conclusions about engineering challenges and solutions.

Authorial particularism is most evident in the skewing of many of the problems and solutions to well-off members of post-industrial nations. Put bluntly, many of them are wealthy Americans’ problems. Some of the challenges (e.g. perfecting virtual reality and reverse-engineering the brain) are simply irrelevant to poor populations struggling to access basic human and social necessities (e.g. food, shelter, voting rights, education and job training). As Riley and Slaton both discuss, some of the challenges are relevant to most populations (better education and healthcare) but the particularistic solutions offered are aimed at those who already have access to the best education and healthcare available. Individualized computer learning, for example, seems irrelevant in classrooms struggling to afford textbooks and pencils, let alone laptops, for students (Kozol, 1991; Riley, this issue), and the perfection of personalized healthcare à la implantable microchips seems out of touch in relation to the millions of people around the world without access to basic antibiotics (Slaton, this issue).

The committee’s choice to prioritize these aspects of education and healthcare—presumably because they bring opportunities for complex and innovative engineering design—is not without consequence for social justice. The uptake of the Grand Challenges report by policymakers may mean that millions of research and investment dollars follow these particularistic solutions. Not only do the solutions suggested in the Grand Challenges ignore the plight of the underprivileged, but very real monetary and political capital investments inspired by this report could make health and education gaps between the wealthy and the poor (e.g. Deaton, 2003; DeNavas-Walt, Proctor, & Smith, 2007) substantially greater, not smaller.

**Double Standards: Acknowledging Engineering’s Contributions to Solutions, Not Challenges**

Second, several authors in this issue see a blatant double-standard in the Grand Challenges’ conceptualization of engineering’s role in the fourteen challenges. The report denotes the heroic role engineers play in addressing the problems facing modern societies, providing key technological solutions that can propel “civilization” beyond these challenges. However, there is no acknowledgement of the contributions of engineering design to the existence of these challenges in the first place. Several authors give examples of these double standards: Riley points out that the Grand Challenges authors write about the grave dangers of nuclear terror, but steer clear of
acknowledging engineers’ role in the Manhattan project which developed that very technology (also see Florman, 1994). The threat of biological weaponry, designed by engineers in state-funded laboratories, is discussed in a similarly one-sided manner. Blame for these problems are placed squarely in the laps of others (e.g. “terrorists,” “cyber criminals”) or are considered the effect of unchangeable social mores (e.g. “It remains unlikely that fossil fuels will be eliminated from the planet’s energy-source budget any time soon” [Grand Challenges p. 3]). There is little acknowledgment of engineers’ contributions to these challenges—either through their design work, or their complicit participation in the socio-technical systems that perpetuate these challenges.

This double standard ignores the half-century of critique of technological change in general and the critique of the development of nuclear and biological weaponry in particular. As Slaton notes, there is a long history of critique of engineering work, from post-World War II fears over nuclear technology to current concerns about the environment. Grand Challenges is written as though it were in the midst of the era of the technological sublime at the turn of the 20th century (Nye, 1992, 2006). But, even Samuel Florman states in his decidedly sympathetic ode to the profession, The Existential Pleasures of Engineering,

The plaintive call for a new engineering expresses a yearning to return to a time when engineers fancied themselves... ‘redeemers of mankind’ and ‘priests of the new epoch.’ With the religion of Progress lying in ruins about us, we engineers will have to relinquish, once and for all, the dream of priesthood, and seek to define our lives in other terms. (1994, p. 41)

Social change in the 1960s and 1970s that ushered in a more critical understanding of technology (Herkert, this issue) makes it no longer possible for engineering to remain blissfully unselfconscious about their profession’s contributions to the central challenges societies face, including those documented in this report. Yet, because of the emphasis on objectification and lack of contemplative epistemologies (Catalano, this issue), engineering’s cultural perspective on its own work would struggle to recognize past and present engineering works as anything but heroic acts of technological prowess.

More consequentially, as Nieusma and Tang argue, this double standard immunizes engineering from the need to take a critical look at its practices of problem definition and solution. Ignoring the profession’s contributions to these challenges allows engineering to remain relevant to society and to protect its claim to being the “saviors” of “civilization” from climate change, cyberterrorism, etc, while at the same time extracting itself from blame—as well as from any responsibility to engage in legislative and policy decisions about the consequences of engineering work for social justice (Nieusma & Tang, this issue).

Bracketing the “Social” and “Political” from the “Technical”

Related to—and partly undergirding—the double standard in the Grand Challenges report is the explicit extraction of “technical” matters from the social, political, ethical and cultural realms of these challenges. Grand Challenges simultaneously positions the engineering profession with sole responsibility for strictly technical factors embedded within those challenges while bracketing (or simply ignoring) the non-technical matters, such as social justice, that are inextricably linked to such “technical” dimensions. This separation of the “technical” from the “social” is part of an enduring propensity in the engineering profession for dualistic styles of thought (Bucciarelli, 1994; Vincenti, 1990). One particular dualism—the “technical/social dualism”—was first identified by Sally Hacker (1981) and expanded by Wendy Faulkner’s work (2000, 2007). According to this cultural belief, purely “technical” tasks and knowledge can be extracted from the “messiness” of the
social world, and such technical realms are most prestigious and meaningful to engineers. Social or political considerations beyond cost efficiency are not only devalued, they also threaten the “purity” of engineering work (Cech, in press).

As many of the authors in this issue argue, this dualism plays a starring role in the *Grand Challenges* report. Not only are the solutions to the stated problems exclusively technological (e.g. desalination as a solution to water shortages), they rarely mention the need for engineers to engage with policy makers and other professionals to deal with the dimensions of these challenges that are considered outside the “technical” realm. This particular framing translates vastly complex social problems into strictly technical problems (Catalano, this issue; Nieusma & Tang, this issue). Such framing suggests a rather profound lack of understanding of the complexity of these challenges, particularly the ways that technological solutions are always inherently interwoven with larger socio-political contexts (Hughes, 1987; Mackenzie, 1990; Pinch & Bijker, 1987). As such, both the definition of these problems and the proposed solutions to them are naive at best and dangerously reductive at worst (Riley, this issue; Slaton, this issue).

As a result of this bracketing, there is little emphasis in the *Grand Challenges* report on engaging the expertise and skills of other professionals (political scientists, sociologists, historians, science and technology studies scholars, ethicists, etc.) to solve problems cooperatively. These professions are certainly not making any claims to the jurisdiction of engineering work, so they are not an immediate threat to the relevance of engineering to society. However, the rhetoric of the *Grand Challenges* resists recognizing that other realms of expertise are necessary and important for addressing these challenges. Consequently, expert (and non-expert) voices promoting social justice are excluded from engineering conversations.

More troubling, Nieusma and Tang and others point out that not only are the contributions of various “social” or “political” constituencies ignored, they are understood as roadblocks to engineers’ work (Riley, this issue; Nieusma & Tang, this issue). The introduction to *Grand Challenges* states that “government and institutional, political and economic, and personal and social barriers will repeatedly arise to impede the pursuit of solutions to problems” (pg. 6). Nieusma and Tang quote sections of the *Grand Challenges* report talking about how teachers “must revamp” their pedagogies so their students benefit from computerized learning, and medical professionals will “have to alter” their procedures to make the best use of health informatics. The *Grand Challenges* report is, therefore, a call for professional action that puts engineering in a position of dominance over opponents, those with competing viewpoints, and neutral bystanders alike. By bracketing and, in several cases, demonizing the social, political, ethical and cultural dimensions of these challenges, the *Grand Challenges* report misrepresents the complexities inherent in the challenges themselves, but also shuts down democratic, social justice-oriented avenues for technological decision-making.

**Technological Determinism**

The final theme and perhaps most potent critique leveled at the *Grand Challenges* by the authors in this issue is a critique of the particular (and particularly narrow) definition of *progress* used in the report. As might be expected from the valuation of the “technical” above all else within engineering culture, *Grand Challenges* understands progress as a purely technological matter. The report’s introduction defines the progression of “civilization” as a steady march toward technological change that results in the antiquation of existing solutions by ever more complex and interconnected technological objects and systems. This technological progression is assumed to be desirable, necessary, and *inevitable*.
Herkert (this issue) discusses literature that labels this perspective “technological determinism” (see e.g. Smith & Marx, 1994). Technological determinism has historically been the predominant way the engineering profession has understood progress (Hughes, 2005; Slaton, this issue), likely because such determinism elevates the engineering profession to prime societal importance. Of course, technological determinism has been criticized as a way of understanding societal change since the 1970s. Historians and science and technology scholars have long argued that understanding societal change as the result of a string of successful inventions belies the social embeddedness of the invention process, and ignores the fact that technologies have no inherent agency or meaning (Hughes, 1987; Marx, 2000; Pinch & Bijker, 1987). Not to mention, technological deterministic definitions of progress ignore religious, political, environmental, and cultural factors that are interwoven in societal change.

Technological determinism is problematic not only because it is a highly inaccurate depiction of societal change, but also because it closes down any room for questions about whether these endeavors should be undertaken in the first place. Riley notes the lack of ethical considerations in both the ends (should these be the challenges we address?) and the means (should these be the particular—and particularly technical—solutions we attempt?) in solving the grand challenges. If technology is understood as the basis of human progress, then such questions are, by their very nature, illogical. Herkert gives an example of how urban development in the mid 20th century, understood then and now as a sign of “progress,” was tremendously destructive to local communities and created more, not less, inefficiencies.

Finally, the Grand Challenges’ presentation of social change through technological determinism means that any negative consequences of that change are considered the unfortunate but necessary fallout of a process whose long-term benefit outweighs any short-term harm. As such, social justice considerations over who must shoulder the burden of this “progress” are seen as largely irrelevant. But asking in whose backyards the radioactive dust from fusion will be buried, or who is to be displaced when urban infrastructure is revamped should be central to decision-making about solving these challenges, not tangential to them (Herkert, this issue; Riley, this issue). The Grand Challenges’ technological determinism leaves no room for social justice discussions, let alone considerations of how important societal challenges might be solved with low-tech, simple solutions, or without technological change at all.

**IMPORTANCE OF REFLEXIVITY AND BROADENED PARTICIPATION FOR SOCIAL JUSTICE**

Together, the critiques offered by the authors in this issue call for two interrelated changes: increased reflexivity, especially about the relation of engineering to social justice concerns, and broadened participation in engineering problem-solving. First, they point to the need for reflexivity—a critical examination of engineers’ role in the past, present and future of societies—in both problem definition and problem solution. For the former, Catalano, Herkert, Riley and Slaton argue for the need for engineers to recognize the full spectrum of factors (technical and non-technical) related to each problem. Asking, perhaps, what non-technical components of these problems inform the role that engineers should (or should not) take in helping to address them (Catalano)? Whose interests does solving the problem serve (Riley)? And, is it really ethically more imperative to seek solutions to these problems rather than other problems (Herkert)? Finally, how can the most egregious areas of a particular problem be identified in a way that considers the welfare of all people, not just those funding or seeking profit from the solution to those problems?
Second, the scholars here call for reflexivity and broadened participation in the pursuit of solutions to these problems. Who shoulders the burden and who benefits most from any given solution (Herkert, Riley, Slaton)? How can social justice and peace displace profit-making as central metrics in problem-solving decisions? Additionally, how can the expertise and experience of non-engineers be incorporated into the problem-solving process? The voices of other professionals and the broader constituencies impacted by those solutions should be included at various stages in the process.

In both problem definition and solution, reflexivity and inclusion of non-engineering voices requires that engineers recognize and embrace the uncertainty and complexity inherent in the challenges they seek to address (Nieusma & Tang, this issue). Only by recognizing and being comfortable with the limits of their expertise can engineers actually “help the people and the planet thrive” (p. 1), not just some people, on some parts of the planet.

CONCLUSION

The Grand Challenges report represents a relatively rare and important moment when the engineering profession (or at least the thought leaders entrusted to speak on the profession’s behalf) offers its views about its role in society. As an artifact of the professional culture of engineering, this report provides the opportunity to examine these views and the cultural values, norms, and visions of engineering embedded therein. The critiques offered in this issue—the central themes of which I describe here—are more than just critiques of a single 50-page document. They are critiques of the engineering profession itself. The popularity and prominence to which Grand Challenges has risen makes these critiques all the more timely, relevant and important for work at the intersection of engineering and social justice.

REFERENCES


ARTICLE

Engineering Improvement:
Social and Historical Perspectives on the NAE’s “Grand Challenges”

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The list of engineering "Grand Challenges" lately developed by the National Academy of Engineering enters a long historical tradition of such epically scaled to-do lists, dating back to the profession's U.S. origins in the mid-19th century. The mission statements, codes of ethics, and, later, lists of so-called grand challenges that have issued from engineering societies have served the dual function of directing engineers' work and supporting particular cultural roles for these bodies of experts. Almost all such plans, regardless of period or sponsoring body, have also blended highly practical aims of industrial and infrastructural development with more inchoate projects of societal uplift. The Grand Challenges of the NAE, currently playing a formative role in many engineering organizations and research and teaching settings, extend this lineage, working from a selective and self-confirming view of human welfare. We might bring to the Grand Challenges the type of critical, politically informed analysis that historians and STS scholars have brought to other sites of engineering activity and professionalization, to detect the nature of interests that underlay all such projections of engineering's role in society. Who is served by the development of different technologies, products, and infrastructures? Who might be harmed? Most fundamentally, the Grand Challenges proceed from the premise that engineering research, construction, invention, and production are to take precedence over their absence, as befits a body dedicated not to the contraction of such enterprises but to their extension. Yet the interests of sustainability, global health, and other areas of human well-being might be best served in certain cases by just such a turning away from engineering. Making explicit the social and historical assumptions of the NAE's Grand Challenges, and probing the implications of those assumptions for a diverse range of actors and communities, may pave the way for more thoughtful engagement with the humanistic and democratic potential of engineering.

KEYWORDS: agency, engineering history, Grand Challenges, National Academy of Engineering, progress

INTRODUCTION

The Grand Challenges for Engineering lately developed by the National Academy of Engineering, with their excited inducements for 21st century engineers to "Reverse-engineer the [human] brain," "Make solar energy economical," "Restore and improve urban infrastructure," "Enhance virtual reality," and undertake ten other tasks, enter a long historical tradition of such epically scaled to-do lists (National Academy of Engineering, 2008). As early as the 1850s, as the first formal organizations of American engineers took shape, the individuals involved sought to project long-term goals and professional guidelines for their groups. The mission statements, codes of ethics,
and, later, lists of so-called grand challenges that have issued from engineering societies and other entities have served the dual function of directing engineers' work and supporting particular cultural roles for these bodies of experts (Christie, 1922; Downey & Lucena, 1994; Kline, 1995; Pfatteicher, 2003; Wisnioski, 2009). They have spurred countless responses and refinements among engineering subspecialties.

Almost all such plans, regardless of period or sponsoring body, have also blended highly practical aims of industrial and infrastructural development and more inchoate projects of societal uplift, of human betterment. While these prescriptions surely have arisen as part of American engineers' historical efforts to demarcate their occupation from those of artisans and scientists, it is the lists' implied social and moral authority I want to probe. We can see that implication of authority as one element of engineers' status-seeking strategies (alongside claims of technical and economic efficacy), as those strategies have been described by Ronald Kline (1995). It is an element that powerfully ascribes universal human value to the intentions and products of engineering labor. As Matthew Wisnioski frames this historical pattern, "By its very nature, engineering is a normative practice" (2009, p. 753), and since at least 1918 designers of engineering curricula have explicitly called for social and humanistic instruction. The Grand Challenges of the NAE, currently playing a formative role in many engineering organizations and research and teaching settings, extend this lineage (Aronowitz, 2010; Azarin et al., 2008; Taylor, 2007; Zappas, 2008). Their integration of economic and productive goals with explicit ideals of social and cultural welfare derives from historical precedents described in this paper.

A perspective informed by the history of technology or by methods of Science, Technology and Society allows us to see not just conceptual continuity among such lists over time, but also their inherent social purposes. The NAE's recent Grand Challenges project, like many earlier prescriptions for engineering practice in the United States, posits extraordinarily broad societal benefits of engineering, using very selective logic to do so. A host of social differences, representing diverse occupational, economic, and global interests, disappear in its unalloyed endorsements of engineering as guarantor of material productivity and solution to human deprivation and suffering. The 2008 publication of the Grand Challenges culminated several years of research and review, including the Academy's 2007 solicitation of ideas from the public through a dedicated website. The composition of the final recommendations and oversight of the entire process were undertaken by "leading thinkers" drawn by the NAE from private industry and academia; eighteen people "dedicated to improving quality of life around the globe" constituted a main committee while some forty-eight additional NAE or NAS members and other prominent figures served as reviewers (NAE, 2008). The sense of professional and social prominence being re-inscribed through this project is strong; everyone listed bears the imprimatur of a prestigious university or established corporate or financial entity. The 1,000 suggestions made by the public obviously reflect only those of people who knew of and accessed the NAE's website, not a wide swath of humanity, but whatever the content of those suggestions, the final list of Grand Challenges nowhere diverges from a self-congratulatory outlook. It nowhere acknowledges that engineering has long brought differential impacts to persons of higher and lower socioeconomic standing in the U.S. and the world. It asks no questions about existing geopolitical advantages or corporate profit structures supported by engineering.

Another type of divergence is also elided in the Grand Challenges document: the ideas of the many engineers inclined to raise such concerns about undemocratic features of their field. Although commendations for NAE's efforts and for the list itself are easily found among engineering groups (Aronowitz, 2010; Azarin et al., 2008; Taylor, 2007; Zappas, 2008), we can understand the creation of the Grand Challenges to have been a consensus-building exercise rather than a reflection of
universally held aims among American engineers. Amidst this project of professional self-definition, any possibility of systematic self-critique by engineering is blunted by the document’s totalizing claim that, “Throughout human history, engineering has driven the advance of civilization” (NAE, 2008). However well intentioned, the NAE’s Grand Challenges, as was the case with earlier examples of such lists, forward some ideas of human betterment and not others, some unexamined notion of what might constitute “advance.” With this paper I want to highlight the extremely robust nature of uncritical depictions of engineering over the last 100 years, and the enduring marginality within engineering of voices that seek to identify the interested features of that discipline. My aim is to show that qualifying statements which might alert us to the potential limits of engineering as a force for humanistic reform or to the field’s negative effects on human welfare do exist, often side by side with strongly positive statements. However, the sweeping nature of positive claims about engineering, such as those framed in the NAE’s list of Grand Challenges and its historical precedents, help discourage critical assessments of engineering and its products. Instead, we can envision a mission statement or list of priorities for engineering that is conducive to self-critique in this influential field, and crucially, free of occupational risk for those who wish to engage in that self-critique.

CHALLENGING THE CHALLENGES

The NAE’s Grand Challenges project a vision of an audience for engineering, and for the document itself, that is above all unified. The document opens with a powerful association of engineering with universal human benefit:

In each of these broad realms of human concern—sustainability, health, vulnerability, and joy of living—specific grand challenges await engineering solutions. The world’s cadre of engineers will seek ways to put knowledge into practice to meet these grand challenges. Applying the rules of reason, the findings of science, the aesthetics of art, and the spark of creative imagination, engineers will continue the tradition of forging a better future. (2008)

Throughout the 56-page document, which specifies the need for engineering attention to each of the fourteen challenges, similar formulations assert that scientists and engineers engage in a “great quest for understanding many unanswered questions of nature.” Such invocations of the inherently praiseworthy character of American engineering, as it has been practiced both in the past and present, draw on generations of similarly selective timelines of human accomplishment (Kline, 1995). A few representative quotes (thousands more are readily found in textbooks, newspapers, speeches, and policy documents across the 20th century) reflect this enduring framing of technical enterprise as invariably a welcome contribution to general human welfare. In 1923, a journalist’s profile of General Electric president Gerard Swope noted that the American engineer promises “industrial well-being, of creating greater happiness through the wider distribution of nature’s gifts and resources, and through a general furtherance of the march of civilization” (Adams, 1923). Prominent civil engineer William Barclay Parsons, then supervisor of subway construction in New York City, told an audience at Columbia University in 1927 that, “should our civilization perish, its ruins, if excavated, will disclose that it rested on engineering” (“Visions,” 1927). General Parsons surely had immediate, perhaps careerist reasons to make such claims for his discipline, but not only engineers raised these points. That same year, the editor of Nation’s Business told readers that the engineer “designs the useful harness for power, conquers the earth and the water under the earth [and] prospers the works of physicist and chemist . . . .” to function as nothing less than “the prodigious servant of mankind” (“Chips,” 1927). In 1938, the author of the popular text, Builders of Civilization: The Story of Engineering, proffered “. . . an arresting account of the triumph of the modern engineer,” who with scientist and inventor does nothing less than “drive back the brute darkness of ignorance by the light of civilization” (Bennett, 1938, front cover).
UCLA economist Dudley Pegrum in 1944 added a note of historicity to such claims by naturalizing the application of engineering to capitalist culture:

The resources which constitute the basis of man’s economic life are labor, the gifts of nature, and accumulated wealth. The dominant characteristic of the last two hundred years of western civilization has been the amazing expansion of man's capacity and the consequent growth of population enjoying a standard of living heretofore unknown. The basis of the great change we call industrialization has been the application of physical sciences to the production of economic goods. (p. 158)

This kind of language gained wide resonance during and after World War II by outlining a close fit between processes of human cognition and presumably universal ambitions for material prosperity, reflecting a long-developing American faith in applied scientific knowledge, as has been described by Kline (1995). A collectivity among all those who live with and around the products of engineering was routinely asserted in this kind of formulation. General Motors headed a 1945 magazine ad with the phrase: "Progress More Quickly," assuring readers that its new technical research center in Detroit would "bring about MORE and BETTER THINGS FOR MORE PEOPLE (original capitalization)." In 1948, Gulf Oil promoted the work of its refinery engineers with ads claiming that its engineers were "well aware that there is a 'plus' for everyone in petroleum's progress." Undeniably, wartime had brought a certain urgency to encouraging public faith in American industry and infrastructure, but this was lasting rhetoric about the assured benefits of engineering beyond immediate national security needs. Western imperialism had long rested on dovetailed images of technological modernization and universal human uplift, albeit uplift that would deliberately bring variable improvement to the lives of persons seen to be of different races or nationalities (Adas, 2006; Anderson, 2002; Mrazek, 2002). For some, the geopolitical realignments wrought by the war seemed to call for a reassertion of older views of American technological hegemony. Writing in 1950, John Charles Lounsbury Fish opened his treatise on "The Engineering Method" by quoting in full a 1925 presidential address by William Frederick Durand to the American Society of Mechanical Engineers, in which Durand reminded his audience that "we are engineers and as such hold a position of peculiar trust and responsibility in connection with the progress of civilization" (p. 1).

In many of these endorsements, whether corporate, journalistic, popular, or scholarly, the sheer variety of engineers' contributions invoked by the writers affirmed engineers' value to society. A 1942 book written for young people, part of the "Way of Life Series," describes the products of the civil engineer's labor:

... a new sewerage system stem, or a water supply improvement for your own home town. It might be a railroad plunging through forests, deserts, swamps, and mountain, where finally you see the shiny rails leading on and on before the eye. Or canals to make a desert green; dams to harness the white horses in a mountain stream and turn their ageless energy to electricity; a pipeline to bring oil or gas to a large city or seaport... And the loftily beautiful skyscrapers reaching for the clouds depend for their sturdy assurance on the skill of the civil engineer. (Bennitt, 1942, p. 6)

If the scope of engineers' contributions to humanity was wide in such depictions, the origins of engineering were also seen as fortuitously heterogeneous. In 1954, Linton Grinter, preparing his seminal report on engineering education, described the field as resolutely synthetic, applying while transcending the "methods of mathematics, physics, and chemistry" by merging those methods
with "engineering art in a professional way to provide for the convenience and welfare of the public" (p. 259).

As I will discuss below, the 1960s began to see a pronounced concern among public and some expert groups about the impacts of modern science and technology on human society and the planet as a whole, which continued as an identifiable movement through the early 1980s. Yet the self-descriptions of engineering institutions maintained a thread of sweeping positivity about the field’s contributions to the human condition, in some instances by minimizing the real world origins and impacts of technical knowledge. New knowledge has thus been cast in these self-descriptions as inherently desirable. Five and a half decades after Grinter's report appeared, the NAE's Grand Challenges echo his correction to the popular misapprehension that, "scientists and engineers have distinct job descriptions" when in actuality, the NAE's document explains,

... the distinction is blurry, and engineers participate in the scientific process of discovery in many ways. Grand experiments and missions of exploration always need engineering expertise to design the tools, instruments, and systems that make it possible to acquire new knowledge about the physical and biological worlds. (2008, p. 48)

The continuity between historical ideas about engineering and those found in the 2008 Grand Challenges, and the uniform commitment across the decades to a final and positive judgment regarding an entire area of human endeavor, is fascinating to the cultural historian. How can such a sense of assurance possibly have persisted in the face of cultural change? For one thing, we assuredly feel, albeit impressionistically, that in our own lifetimes we have a fuller understanding of human culture than did people of previous generations, that knowledge about our human culture somehow accretes. Otherwise the experience of being "modern" would have no meaning. Much of the language used in essays of 1927 or 1957 sounds florid and fusty to our ears; we might wonder: "how can the ideas expressed since that time not also have changed?"

Perhaps more concretely (and defensibly), we might simply observe that in the early 21st century we have the benefit of many counter-arguments that have drawn our attention to the questionable benefits and manifold risks of engineering (Sismondo, 2008). As the existence of this journal itself indicates, engineers contribute to that critical perspective. Yet those critiques have not obviated messages, such as that delivered by the Grand Challenges, asserting the collective good inherent in engineering; we might take a moment to try to understand why not.

**PROGRESS AND CRITIQUE**

Critiques of industrialization issued from 19th century American philosophers and critics with the first factories, but during the Great Depression and World War Two these analyses perpetuated. At mid-century it was not just well known figures such as Lewis Mumford and J. Robert Oppenheimer but many progressive writers and thinkers who saw science as fueling the "harmful factors and effects" of industrialization and geopolitics, one economist summarizing that "the control and direction of scientific progress should be considered wishful thinking" (Slaton, 2010; Sullam, 1942, p. 393). In a great many cases academic critiques of mainstream science and technology and public sentiment built on one another. During the final third of the 20th century, Americans encountered not only Rachel Carson, but highly organized anti-nuke, back-to-nature, and environmental movements in their own communities. Influential figures such as Herbert Marcuse, Jacques Ellul and Theodore Roszak supplied a literature on which countless college courses' syllabi were based. By 2008, "eco" sensibilities had revitalized in the face of global warming and catastrophic oil spills. Anti-industrial activists, while fewer in number than in Europe, organized around U.S. meetings of
the World Trade Organization and similar bodies felt to be responsible for the worst environmental transgressions and economic inequities of globalizing capitalism (Wisnioski, 2009; Sismondo, 2008). Recent critical studies have also incorporated growing concerns about the privatization of the American university and worrisome exertions of influence by industry on academic scientists (Croissant & Smith-Doerr, 2008; Newfield, 2008).

It is thus apparent that American culture regularly generates doubts about the safety and democratic potential of science and technology, and that for some citizens at least, those activities are no longer imagined to be tethered to a positivist science in ways that once supported unidirectional, entirely upbeat narratives about human ingenuity (Appleby, Hunt, & Jacob, 1995). Matthew Wisnioski and Rebecca Slayton offer particularly suggestive accounts of experts from within science and engineering who have experienced such doubts (Wisnioski, 2009; Slayton, 2004). So the historical question for me, in the face of the NAE Grand Challenges, is not how optimism about engineering can persist; engineers today make tremendous contributions to human welfare through both dramatic innovations and the routine work of designing, building, and manufacturing our material reality. Rather, the question is how it is that unalloyed praise for engineering can persist, as seems to be the case through much of the Grand Challenges document and as is very much the undertaking's overall impression.

Crucially, I am not seeking a singular, let alone dismissive, evaluation of the Grand Challenge's intent and/or outcomes. The document has value to any society that hopes to spread the benefits of health, shelter, and ease of living that technologies can provide. It gathers persuasive arguments for the application of ingenuity, energy, compassion, and inclusive impulses towards those ends. Such impulses have always been part of the motivation and function of engineering in the United States. In an important sense, however, all self-defining projects undertaken by authoritative scientific bodies (for example, any such report issued by the National Academies) might be said to be more or less concerned with reputation. This is in fact true of all expert practice, but as historians of science have demonstrated, the norms of Western science discourage explicit or implicit acknowledgement of the field's subjectivity, let alone fallibility, by that field's practitioners and patrons. To the contrary—it is observers' trust in scientific practitioners that lends a sense of facticity to those practitioners' findings. (Shapin, 1994). In the same way, the Grand Challenges both presumes and helps to create trust of engineers among readers by foreclosing any discussion of doubts about engineers' knowledge or practice.

This is by no means to say that the NAE is not trustworthy, but the organization's production of reliable, definitive engineering knowledge necessarily includes the production of trust. For the authors of the Grand Challenges, that creation of trust is apparently (and regrettably) a process to be devoid of criticality or debate. This is a deflection endemic in Western engineering: As Sarah Pfatteicher has shown, codes of ethics that historically have urged engineers to practice only within the limits of their own competence have rarely defined those limits clearly. In this way engineers have made their own standards of competence more or less loose, but also, crucially, made them virtually impossible for non-experts to apply (Pfatteicher, 2005; Slaton, 2001). We could add that these efforts to demarcate the competence of engineering sub-fields virtually never suggest that engineering as a overall category of practice may hold risks for human society (Pfatteicher, 2005). I am drawing critical attention to the near complete absence in the Grand Challenges of points that might suggest any such practical uncertainty or social complexity. I hope to encourage greater openness in our everyday thinking about what engineering has done, historically, and what it can do (Brown, Downey, & Diogo, 2009).
SELECTIVE DEPICTIONS OF AMERICAN ENGINEERING

In order to draw this more nuanced and open-ended picture of American engineering, we can start by identifying ways in which the Grand Challenges direct our attention away from flows of power and privilege in technical practice. This occurs in part because the Grand Challenges document does not refer to the complex social conditions of its own creation. To take an example, who participated in the writing of the document and who did not, and in what capacity? Readers are provided with a list of names of those who served on the "diverse committee of experts" responsible for the document’s content. We are told that they are "some of the most accomplished scientists and engineers of their generation," whose work was then reviewed by "more than 50 subject-matter experts." Some of the names are instantly recognizable as prominent inventors and entrepreneurs, their fame confirming their accomplishments in those particular realms. But we learn nothing of these participants' experience (if any) in the study of societal impacts of engineering, their ideological standpoints, or their relative influence on the composition of the document. We know nothing of what counted as valid expertise in the creation of the Grand Challenges, let alone as credible "worldwide input" from persons or publics deemed to be non-experts by those in charge of the report (Zappas, 2008). Critical engineering studies of the last decade demonstrate that participation in engineering enterprises is largely determined at the major points of entry into engineering, such as public education systems and universities, and professional work settings. These institutions do not yet represent all sectors of our society equally; persons of minority and economically disadvantaged background and, in many instances, women are still underrepresented. It is not clear if or how the production of the Grand Challenges addressed these discriminatory conditions of expertise (for a summary of this scholarship see Brown et al., 2009).

We should draw no simple equivalence between such current exclusionary habits and those of earlier generations. We no longer traffic in crudely racialized presumptions about the innate technical talents of different groups, as that evident in the 1927 magazine profile of Gerard Swope, mentioned above. In that piece, Swope was said to be identifiable as the perfect "idealistic engineer" in part because he possessed "thin lips often pursed in thought when in repose" and "sharp clean-cut features," both traits invoked in opposition to the facial features thought to signal non-white genetic heritage (Adams, 1923). However, we do use unexamined criteria (standardized tests, adherence to certain curricular experiences) to judge the talent of aspiring engineering students, and those criteria reassert lines of racial and class differences (Purdy & Wasburn, 2005). And, while we would assuredly not propose today, as did an engineering textbook of 1916, that the engineer must not only be male but also be committed to a "normal family life," homophobia persists in engineering (Cech & Waidzunas, 2011; Pawley & Tonso, 2010; Slaton, 2001). Identity constrains opportunity in engineering in many ways. In its claims of definitive knowledge about what constitutes human welfare (the "grand" of "grand challenges" perhaps), uninflected by such issues of identity and inclusion, the NAE’s document reifies socially constructed and socially impactful definitions of expertise and "forward edge" technological practice.

Relatedly, despite what I must presume to be sincere concern with the well-being of all who live with the products of engineering, the interests of many non-expert communities are set largely out of view in the very formulation of the fourteen Grand Challenges. They are simply not part of the "story line" of engineering here (Martin, Scott, & Strout, 1995). For example, consider the recommendation that engineering fields make it a priority to "Engineer new medicines." We learn in the NAE document that personalized medicine, building on genetic and genomic techniques, can increasingly base patient treatment on individual biology. This implies an unprecedented precision in medical practice, but in declaring that precision and customization to be the primary goals of bioengineering, this Grand Challenge also empowers researchers’ inattention to the collective social
conditions that in part determine our health. Variable nutrition, exposure to pollutants, and workplace risks among different communities and similar socially conditioned factors in human health are hidden. Individuals, cast by the Grand Challenges authors as fortunate consumers of medical and pharmaceutical innovation, are not authentically empowered by these developments because they are not given the option of choosing effective preventive strategies.

Again, I don’t deny the tremendous benefits to be derived from the development of new medicines. But a "glass-half-full-or-half-empty" framing of these matters forecloses constructive conversation, and those benefits will be limited if we ignore the larger social world in which pharmaceutical and bioengineering innovation occurs. The totalizing claims of the document overall for the beneficial impacts of engineering discourage such a heterogeneous intellectual project. Not least worrisome is the elision in this Grand Challenge, however inadvertent, of engineering’s role in causing illness. For example, agricultural engineering and food processing techniques of recent decades have introduced contaminants into diets that are now understood to produce cumulative exposure and serious risks (Santi, 2010). Science and bioengineering reveal those dangers, but these dangers remain offstage in the Grand Challenges, rendered irrelevant in the contemplation of hopeful portrayals of the field.

The idea that bioengineering might bring mixed blessings for humanity, visible when its impacts are viewed through the largest lens, is not a recent development. Even in 1942, V. B. Sullam could write concernedly of Ehrlich’s pharmaceutical discoveries in light of globalization:

A world free from syphilis, from meningitis, from pneumonia . . . What else could we dream of? But, with tropical diseases held in check new frontiers would be open in Asia, in Africa, in South America, and agriculture would become unprofitable in the OLD World; new and tremendous problems would arise. (p. 393)

Sullam stresses the interdependency of global markets to convey the mixed impacts that a scientific “advance” might have on different populations, rather than assert some falsely unified if familiar picture of human welfare. But such concerns about technical enterprise are almost always developed and shared outside of engineering disciplines themselves, or compartmentalized within engineering as humanistic or policy aspects of technical work, rather than as reflecting conditions that might be generative of engineering work itself (here Riley, 2008, is extremely helpful).

We might consider the Grand Challenge to "Prevent nuclear terror" to embody this pattern. The document articulates the staggering dangers of nuclear technology falling into the hands of terrorists, but then completely disaggregates that misapplication of nuclear knowledge from the institutional and intellectual developments that give rise to legitimate incarnations of nuclear energy. That is, the Grand Challenges initiative fails to acknowledge that legitimate activities in this case are a precondition for illegitimate activities. American policy makers are currently advocating for the expansion of nuclear power production on the presumption that security is a surmountable matter; we are not attempting to solve the security problems before proceeding. The Grand Challenges’ authors acknowledge that, "Ensuring that a nation using nuclear power for energy does not extract plutonium for bomb building is not easy," but the larger framing of how such high-risk situations arise in part through the participation of engineers is not an element of the Grand Challenge discussion. While the discussion of another Grand Challenge, "Securing cyberspace," gives much more attention to shortcomings in technological realms ("The problems are currently more obvious than the potential solutions"), the occupational, institutional, and market forces that have brought about that situation and that may impede its improvement are not addressed.
THE AGENCY OF ENGINEERS

It seems reasonable to conclude that if leaders of the American engineering professions, such as the NAE, put such forces at the center of their analyses and recommendations, the work of engineers might begin to include inquiry about the social origins and impacts of that work. Defining engineering problems in light of such up-and-downstream conditions would require a concerted shift in the field; in no engineering job description that I know of appear the words, "Determine the broadest social and political conditions in which you perform your technological tasks and act accordingly." Such a work requirement sounds absurd to our ears, but that sense of absurdity in fact arises from a culturally specific idea of engineering which can be challenged. Similarly, it is easy to picture how engaging in that kind of institutional contextualization could lead to arguments against the necessity of one’s own employment; without some newly imagined sort of job security the risks to engineers who participate in such self-critique are immense. But some if not all engineers historically involved in humanistic reforms surely have had just such profound recalibrations in mind, despite such impediments as the entrenched instrumentality of the field, so powerfully described by Seron and Silbey (2009). We might take this opportunity to draw a sharp line between a new sort of social agency for engineers and that customary instrumentality.

The somewhat passive or reactive character ascribed to engineers in the Grand Challenges might discourage the uptake of social and political responsibility by engineers. Despite the authors' repeated appeals to engineers' social values and proactive impulses, in many ways the text conveys that the status quo is acceptable. Consider the Grand Challenges authors' endorsement of engineering work on sustainable energy sources:

*Anticipating the continued use of fossil fuels, engineers have explored technological methods of capturing the carbon dioxide produced from fuel burning and sequestering it underground. (NAE, 2008, p. 3)*

Since one of the fourteen challenges is to "Make solar energy economical," we should not assume that by "anticipating the continued use of fossil fuels" the authors really mean "accepting" that use. And yet, economic context is nonetheless presumed by the authors of the Grand Challenges to determine the value of engineers' research, and thus appropriately to direct that research:

*Engineering solutions for both solar power and nuclear fusion must be feasible not only technologically but also economically when compared with the ongoing use of fossil fuels. (NAE, 2008, p. 3)*

This phrasing posits the relative affordability of technologies as a standard for meritorious engineering research, but historically, affordability has been judged in industrial societies through the lens of corporate profit. Cost saving and profit are notoriously conservative forces in capitalistic economic systems, leaving patterns of material privilege (and disadvantage) intact. As MacKenzie and Wajcman put it, "economic shaping is social shaping" (1999, p. 13). The Grand Challenge authors acknowledge that "engineers' earlier projects have . . . unexpected or negative impacts," but offer all such caveats with so little contextual analysis that these qualifications lose their power to shape the future of engineering.

This orientation towards social and political neutrality seems, to me, to be incompatible with critical assessment of engineering and thus with genuinely democratic practice. Social scientists have demonstrated that patronage (sponsorship of innovation and production) is strongly determinative of the impacts of technology (Croissant & Smith-Doerr, 2008; Mackenzie & Wajcman, 1999; Moore, Kleinman, Hess, & Frickel, 2011; Newfield, 2008). Yet, that element of American
engineering is rendered almost entirely opaque in this document. The bald, celebratory rhetoric of pro-capitalist voices in earlier decades simply attributed our quality of life to corporations. In 1944, economist Ludwig von Mises editorialized that the techniques and products of "Big Business," from "noodles, soap, [and] cigarettes" to "railroads" and "rayon" are characterized by "... an unceasing tend towards improvement" (p. 3). But no such associations, either laudatory or critical, are exposed in the Grand Challenges, as engineering appears in the text to be a service-oriented yet oddly autonomous body of knowledge work. Without some frank discussion of the structures of patronage, how can the NAE’s aim of fairly and deliberately distributing engineering’s benefits possibly be enacted, on either a national or global stage?

A number of historians and social scientists have lately honed in on the idea that engineers are too often cast, even in their own promotional rhetoric, as "problem solvers" rather than "problem definers." In this way, engineering has limited not only its professional status relative to policy and science fields, but also discouraged its practitioners and publics from seeing technological expertise as potentially a politically progressive instrument (Croissant & Smith-Doerr, 2008; Downey, 2005; Slaton, 2010; Wisnioski, 2009). However, even that sort of critical analysis may not offset one of the most powerfully conservative features of the Grand Challenges and similar prescriptive projects: the foreclosure of the possibility that engineering may not be the answer to a social or material problem.

It is the patent function of the Grand Challenges to show the role of engineering in meeting the needs of current and future human societies, but the document’s logic is totalizing in claiming that those needs "await engineering solutions." Andrew Abbott has shown that professions routinely undertake such self-justifying activities to persuade their audiences of their particular utility (Abbott, 1988). But unlike professions with narrower claims to societal benefit, such as accounting, or with humanistic claims confined to a single area of human experience (however grandiose), such as medicine, engineering often articulates an especially diverse social utility. I do not suggest that we assess the relative contributions of different expert groups to human welfare or even the validity of such claims, both ridiculous exercises that would land us in an infinite regress of criteria-setting and evidence-choosing. Rather, if we are concerned with the impact of knowledge production systems on human welfare, we might learn a great deal by studying the precise means by which bodies of expertise attain their credibility. Historically, observers from Thoreau onward have interrogated the universalizing and self-perpetuating logic of industrialization, by which expectations of economic growth demand technological innovation, which in turn begets more economic growth. Engineering demands more engineering, as Mumford made clear. Again, while engineering has surely improved the quality of life for countless individuals in industrialized societies, obscuring this self-perpetuating logic cannot be consistent with thoroughly progressive social ideologies; hence the problem with setting "engineering challenges" in the first place . . . they are predetermined to necessitate more engineering.

Consider in this regard the NAE Grand Challenge centered most clearly on America’s built environment, a call to "Restore and improve urban infrastructure." Happily, in articulating this challenge, the authors do not uncritically call for the replacement of existing structures. Instead, they highlight the creation of new facilities, such as "hubs" that may support the addition of mass transit, bikes, or walking to existing road systems. Yet the document stops short of casting roads as part of the problem so that we might entertain the possibility that fewer built structures in these settings would be better. Certainly, the authors introduce no larger point about the sometimes unsustainable or undemocratic nature of American civil engineering projects. Nowhere do they ask us to think about the legal and policy structures that continue to facilitate the construction of, say, new roadways and suburban developments, long after the ill effects of such sprawl, on both the
environment and urban communities left behind, came to light. Pro-automobile, pro-development, and even pro-business ideologies that balk in principle at limiting any private enterprise in this country will militate against engineering work on such "hubs" even at the funding and design stage, let alone at the technical research and construction stages. As in many portions of the document, mention of "various policies and political barriers" to changes in the aims of engineers is confined here to a single sentence included after and apart from other points, rather than treated as integral, pervasive forces in the built environment (see Nieusma & Tang, this issue). "Political forces" must be marshaled in order for engineers to work effectively, we read, but engineering itself is cast by extension as something other than a political force.

CONCLUSIONS

As neoliberal ideologies gaining credence among American policy makers and politicians tighten their grasp and market forces play an increasing role in Americans' determinations of what counts as worthwhile technological inquiry, it may become more difficult to draw attention to possibly harmful effects of engineers' labor (Brown, 2006). There is a Sputnik-era sense of urgency surrounding Western scientific innovation in 2012, for its promise of both economic and national security applications, and amidst fears of an ostensible "skills gap," an accompanying illogic to doubting the national need for more engineers and engineering (Slaton, 2012). At the same time, since this discussion has raised doubts about the efficacy of what is clearly a well intentioned project, it is worth repeating that on every page of the Grand Challenges, welcome developments in health, shelter, mobility, labor saving devices, and national security as well as directions for further such improvements are instantly recognizable to the engineers, educators, employers or policy makers who are the likely readers of the document.

The suggestive point here, however, might be in those last words: "... the likely readers of the document." How would people of other nations or cultures, outside the usual audiences for NAE recommendations, read this document? Or, persons living in economically disadvantaged American communities that have historically borne the costs, rather than benefits, of the nation's industrial or infrastructural development? The universalizing tone of the Grand Challenges, implying that there are better and worse material projects in which humans might engage but that all humans share the same material interests, supports historical patterns of material privilege and injustice. Technological developments that enhance aspects of my life can have costs for others: my inexpensive household heating comes from the use of coal obtained through mountaintop-removal mining, a process that has caused incalculable environmental and community harm in parts of Appalachia. My ability to purchase inexpensive household appliances derives not only from the genius of inventors, materials experts, and process engineers, but from the low wages of factory workers in other parts of the globe.

The alternative to relentless positivity is not negativity, but criticality, or openness of inquiry. The selective outlook of the Grand Challenges' authors could be recognized as such. The categorization of certain problems as engineering problems might be shifted in helpful ways here. If the Grand Challenges project advocates for the control of chemical weapons, for example, it might also ask what is not remedied when chemical warfare is indeed foiled by nano-engineered detection devices—the sources of geopolitical conflict that give rise to the weapons in the first place. With such a wide lens, defense spending might be reconfigured to include economic development in troubled nations, perhaps through U.S.-led innovation in health and water distribution technologies, say. Or, we might ask, "what is not fixed when American cars run on renewable fuels?" The answer: The economic system that deprives those who do not own cars of proximity to jobs, healthy food, and pleasant communities, and the reification of that system in a road-based
infrastructure. "Why roads at all?" we might ask anew. We need to put the work of engineers (and our expectations of their work) on the broadest possible stage to assess its meaning for human society; flattery gets us nowhere, literally.

These reorganizations of "problems" and "solutions" involve taxonomic change, questions about where engineering begins and ends. These are being asked by historians, sociologists, and policy makers working in the loosely defined field of Science and Technology Studies, but also by those who write about economic equity, environmental history, labor history, and many other subject areas in which engineered structures and systems have had an impact. Activists, as noted above, have also asked these questions as they contend with perceived challenges to health, sustainability, and quality of life in the U.S. and global settings. This paper emerges not from a belief that the authors of the Grand Challenges hold some particular ideological position about health, sustainability, energy production, or any of the geopolitical matters surrounding these areas of human enterprise. Rather, it derives from a powerful sense that the well intentioned authors and promoters of these 21st Century Grand Challenges are operating at a distance from the critical scholarship in which those non- or extra-engineering fields engage (Sismondo, 2008). The document fails to engage with the important historical finding that technical knowledge is necessary in order for technical expertise to improve human welfare, but not sufficient, as historian of urban technology Scott Gabriel Knowles has put it (2011). The Grand Challenges help us set priorities; some projects are more worthwhile than others, without organizing our work we cannot make headway. But questioning the definition of what counts as headway may be the most important challenge of all.

**REFERENCES**


ARTICLE

I Have Seen the Future!
Ethics, Progress, and the Grand Challenges for Engineering

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This article is a critique of the U.S. National Academy of Engineering’s report, Grand Challenges for Engineering, based upon the “technocratic view” of progress as defined by historian Leo Marx and as exemplified by the public works of Robert Moses, including the 1964 World’s Fair, as well as technological determinist narratives on the digital age drawn from contemporary culture. While the so-called Grand Challenges purport to have social aims, a close reading of the document’s overview essay suggests that the technocratic view of progress—which views technology primarily as an end in itself rather than as a means to social progress and fails to explicitly account for engineers’ social and ethical responsibilities—still dominates the thinking of at least some leaders of the engineering profession. This technocratic thinking presents a critical barrier to achieving social justice both within engineering and in the larger world.

KEYWORDS: Grand Challenges, National Academy of Engineering, Robert Moses, progress myth, technocratic view of progress, technology as culture

INTRODUCTION

The future ain’t what it used to be.
-Yogi Berra (Berra & Kaplan, 2002, p. 159)

John, you are a Timex watch in a digital age.
-Thomas Gabriel (played by Timothy Olyphant) in Live Free or Die Hard (Wiseman, 2007)

In the summer of 1964, while on vacation with his father, one of the authors (Herkert) attended the 1964 New York World’s Fair, the creation of the city’s master builder, Robert Moses.1 The fair, whose various themes/mottos were “Peace Through Understanding,” “Man’s Achievements in an Expanding Universe,” and “A Millennium of Progress,” was a tribute to the world-changing potential of technology. Attending the fair was probably a significant factor in Herkert’s decision to study engineering as an undergraduate. Moses’s vision of a world made better through technological progress, though not an original idea, has nonetheless endured through more than four decades of domestic and global struggles for human rights and environmental protection. While Herkert was present at what many writers (Hall, 2002; Jackson, 1987) have called the genesis point of America’s

1 During the same trip Herkert also saw his boyhood heroes, The New York Yankees, play at Yankee Stadium under the leadership of their new manager and former star, Yogi Berra. Berra is well known for his tortured quotations; the one included at the beginning of this article is perhaps his most insightful.
car culture, the other author (Banks) grew up in its aftermath: A native of South Florida, Banks witnessed the frequent and violent car crashes, lack of public space, and never-ending suburban sprawl that automobile-dominated transportation has wrought on the American landscape. Despite a displacement of a few decades and a thousand miles, both authors have experienced Robert Moses's influence on the American built environment.

Moses is known for the ways in which he shaped New York City and its surrounding counties in the 20th century, with his accomplishments serving in turn as a model for engineering, architecture, and urban planning in the nation at large. The son of a successful merchant and real-estate developer, Moses attended Yale and Columbia, obtaining a PhD in political science and entering city politics in New York, where he gained the attention of an advisor to Al Smith, future governor of New York. When Smith rose to power, Moses was granted authority through political appointments for planning bridges, highways, the state parks system, and urban renewal projects (Goldberger, 1981). Marshall Berman described the system put in place as a “network of enormous, interlocking, ‘public authorities,’ capable of raising virtually unlimited sums of money to build with, and accountable to no executive, legislative or judicial power” (2003, p. 141).

Robert Moses was able to defend and justify his authoritarian actions by situating them within a particularly brutal rendition of the progress myth. Berman recalls an infamous Moses quote: “When you operate in an over built metropolis, you have to hack your way with a meat ax” (2003, p. 134). Moses was a product and symbol of his time. His unquestioned power had a cozy rhetorical home within the myth of technological progress. He was able to convince the public that his ax wielding, while seemingly uncaring, was necessary for New York’s long-term survival in the modern era. To oppose Moses was to oppose “modernity itself” (Berman, 2003).

Moses was hacking up the Bronx just as the myth of technological progress was reaching an apex. Over the 1960s and ’70s it would contract under the constant threat of nuclear war, followed by mounting evidence of irreparable environmental destruction. Today, the popular reasoning goes, we are more cynical and suspicious of experts and the technology they bring to bear on perceived problems (Beck, Bonss, & Lau, 2003; Beck, Giddens, & Lash, 1994; Beunen & Opdam, 2011; Bleich, Blendon, & Adams, 2012; Fischer, 2009). Most cultural critics would agree with Franco Berardi when he calls the 20th century “the [last] century that trusted the future” (Berardi, Genosko, & Thoburn, 2011, p. 17) and Kurt Anderson when he says, “the future has arrived and it’s all about dreaming of the past” (2012, Nostalgic Gaze, para. 4). The public is suspicious of large bureaucracies and major technological interventions. The wunderkind expert has been replaced with an ephemeral, almost supernatural, being: the market. The market decides how to proceed—not individuals or organizations. The naturalization of market forces (Graeber, 2011; K. Marx & Engels, 2011) makes claims about the necessity and primacy of cost unassailable.

We see it otherwise. The appeal to abstract market forces and mythical job creators is the same old technological somnambulism in a new wrapper.2 No longer embodied in the visage of one man (e.g., Moses) or even one organization (e.g., General Motors or NASA), the utopian visions of the New York World’s Fair have returned with a vengeance. We contend that Leo Marx’s titular question, “Does Improved Technology Mean Progress?” (2006, p. 3), is more pertinent (and important!) today

2 Here we are borrowing the purposely overly-scientific phrasing of Langdon Winner (1986) who, lamenting the lack of critical philosophy of technology, characterizes most people as “sleep walkers”—unthinkingly reproducing domination and control over others through the implicit and explicit embrace of technology as the solution to perceived problems. Winner writes, “. . . the interesting puzzle in our times is that we so willingly sleepwalk through the process of reconstituting the conditions of human existence” (p. 10).
than ever. A prominent case in point is the Grand Challenges for Engineering\(^3\) report of the National Academy of Engineering (NAE, 2008), which demonstrates that technological determinism is still alive and well in western culture and that the collective faith in technology to solve society's problems has never been stronger. The report's authors' explicit reference to popular depictions of technology highlights not only the continued relevance of Leo Marx's critique of technocratic thinking, but also forces cultural commentators concerned with these aspects of society to broaden their scope when it comes to offering prescriptive conclusions on changing engineering practice. Moreover, we must recognize the importance of scaling aspirations and goals to the appropriate level (Allenby & Sarewitz, 2011). The concept of a “Grand Challenge” must be problematized or new socially conscious and ethical solutions of an equally large scale must be submitted for consideration.

**TECHNOLOGICAL DETERMINISM AND A SEARCH FOR ETHICS**

Today Moses' vision of technology-driven progress is manifest in many forms including the Grand Challenges. It depicts the world's problems as issues of logistics, physics, and economics. There is little room in this vision for the deep sociotechnical complexities that are often at the heart of “Grand Challenges.” The future has proven to be more complex than even Moses could have imagined; it is disappointing to find leaders of the engineering profession still clinging to a vision of progress that does not account for this complexity and fails to make explicit the social and ethical responsibilities of engineers, precluding among other things a meaningful conversation about social justice. The document only briefly loses its “view from nowhere” (Haraway, 1997) in the introduction to the section titled “Secure cyberspace.” This section begins with its one and only explicit reference to popular culture:

Electronic computing and communication pose some of the most complex challenges engineering has ever faced. They range from protecting the confidentiality and integrity of transmitted information and deterring identity theft to preventing the scenario recently dramatized in the Bruce Willis movie “Live Free or Die Hard,” in which hackers take down the transportation system, then communications, and finally the power grid. (NAE, 2008, 40)

While being careful not to overstate our case, we will revisit the significance of this reference, at length, later in the article. For now, however, suffice it to say that the Grand Challenges report is thoroughly and completely a product of a western standpoint. This is not to say that the search for clean water or renewable energy only benefits rich countries, or that virtual reality and cyber security are goals unworthy of research. Rather, NAE's privileged standpoint is belied by the report's inclusion of “Reverse-engineering the brain,” health informatics, and enhanced virtual reality alongside providing clean water and restoring infrastructure. These challenges are presented as self-evident: the obvious problems faced by people today. The authors qualify their choice of challenges by saying, "Foremost among the challenges are those that must be met to ensure the future itself. The Earth is a planet of finite resources, and its growing population currently consumes them at a rate that cannot be sustained” (NAE, 2008, p. 2). While we agree with this claim, it fails (along with the rest of Grand Challenges) to explicitly recognize a role for ethics in engineering decision making.

The overview essay for Grand Challenges does not mention ethics (and neither do all but one of the essays on the fourteen individual grand challenges). This in itself does not prove that the Grand

\(^3\) Editors' note: The capitalized, non-italicized forms of “Grand Challenges” and “Challenges” found throughout this paper refer to the broader body of work stemming from the original 2008 NAE Publication. Where the actual publication is inferred, the terms are presented in italics.
Challenges are bereft of ethical substance. After all, the authors’ avoidance of language of “ethics” may have been deliberate; most teachers of engineering ethics have reflected at one time or another on the barriers that the use of the “E-word” poses for capturing the attention of engineering students and their academic advisers. We may even give the authors the benefit of the doubt and say that ethics runs implicitly throughout the document: What is more ethical than devoting your life to creating optimal levels of “sustainability, health, vulnerability, and joy of living?” The cracks in this reasoning come from a close reading of Grand Challenges’ overview essay, “Introduction to the Grand Challenges for Engineering.” Such a reading reveals an underlying philosophy that Leo Marx (2006) has referred to as the “technocratic” view of progress that either, at best, is indifferent to ethical considerations or, at worst, undermines engineering ethics.

In his well known essay, “Does Improved Technology Mean Progress?,” Leo Marx contrasted the Enlightenment and technocratic concepts of progress. Whereas the Enlightenment concept saw improved technology as a means to achieving social progress, such as the realization of democratic values, the technocratic view sees improved technology as an end in itself: “Over time [the Enlightenment] conception was transformed, or partly supplanted, by the now familiar view that innovations in science-based technologies are in themselves a sufficient and reliable basis for progress” (2006, p. 11).

The technocratic view of progress is clearly on display in the work of Moses, who was responsible for much of New York City’s public works and infrastructure (Obenhaus, 1988). Though a popular figure early in his career, as Moses’s power grew, his projects displaced more and more people and seemed to take on a life of their own. To Moses, Enlightenment democratization was an impediment to technological progress. He often derided his critics as misinformed outsiders and frequently bulldozed structures before those in his path had a chance to seek legal recourse. His technological achievements—Jones Beach, the Triborough and Verrazano-Narrows bridges to name a few—are legion, but many of his projects had deeply problematic social outcomes. While tenements were cleared as part of Moses’s plans to build modern high-rise buildings, viable, albeit poor, communities were destroyed in the process. And projects such as the Cross-Bronx Expressway destroyed vibrant, middle-class communities. The destruction of these communities and the authoritarian processes by which they were carried out represent grave injustices that result directly from the technocratic view.

It is important to acknowledge that even as Moses was in a privileged position to further technocracy, the technocratic view did not and does not exist exclusively among elites. It is reinforced in historical and current U.S. culture by people of all backgrounds and social positions who believe in technological progress as itself sufficient for social progress.

The Grand Challenges introductory essay also adopts a technocratic view, sometimes explicitly and at other times more subtly. Early in the introduction, for example, the document sings the praises of technology and strongly implies that social progress has followed suit:

In the modern era, the Industrial Revolution brought engineering’s influence to every niche of life, as machines supplemented and replaced human labor for countless tasks, improved systems for sanitation enhanced health, and the steam engine facilitated mining, powered trains and ships, and provided energy for factories.

In the century just ended, engineering recorded its grandest accomplishments. The widespread development and distribution of electricity and clean water, automobiles and airplanes, radio and television, spacecraft and lasers, antibiotics and medical imaging, and computers and the Internet are just some of the highlights from a century in which
engineering revolutionized and improved virtually every aspect of human life. (NAE, 2008, pp. 1–2)

The claim that technological progress naturally leads to social progress is hammered home in the introduction's concluding sentence, which states:

Meeting all those challenges must make the world not only a more technologically advanced and connected place, but also a more sustainable, safe, healthy, and joyous—in other words, better—place. (NAE, 2008, p. 6)

To be sure, the Grand Challenges introduction does highlight social indicators engineers can address (i.e., sustainability, health, vulnerability, and joy of living), but true to the technocratic view these benefits are seen as derivative of improved technology rather than being the motivating goals of technological progress. Moreover, it is a rather limited range of indicators. What about justice? Peace? Education? Self-governance?

Curiously, Grand Challenges also discusses a limited range of attributes ascribed to engineers in meeting the Grand Challenges:

Applying the rules of reason, the findings of science, the aesthetics of art, and the spark of creative imagination, engineers will continue the tradition of forging a better future. (NAE, 2008, p. 2)

Here is where the absence of ethics is most obvious in Grand Challenges. There are arguably other missing attributes as well, such as humility, empathy, and interdisciplinary thinking. And note in this last quote a return to the theme of technological progress automatically leading to a “better future.”

Consistent with the technocratic view of progress, and with Moses’s projects, the Grand Challenges introduction reminds us of the technocratic imperative that people must adapt to technological change (and not the other way around):

Public understanding of engineering and its underlying science will be important to support the calls for funding, as well as to enhance the prospect for successful adoption of new technologies. The ultimate users of engineering’s products are people with individual and personal concerns, and in many cases, resistance to new ways of doing things will have to be overcome. Teachers must revamp their curricula and teaching styles to benefit from electronic methods of personalized learning. Doctors and hospital personnel will have to alter their methods to make use of health informatics systems and implement personalized medicine. New systems for drug regulation and approval will be needed when medicines are designed for small numbers of individuals rather than patient populations as a whole. (NAE, 2008, p. 5)

Not only must people adapt to technological imperatives, but the Grand Challenges introduction also suggests that, like the thousands evicted by Moses, people’s goals and desires are obstacles and barriers to technological progress (see Nieusma and Tang, this issue):

Part of the engineering task will be discovering which approaches work best at ensuring user cooperation with new technologies.

In sum, governmental and institutional, political and economic, and personal and social barriers will repeatedly arise to impede the pursuit of solutions to problems. As they have
throughout history, engineers will have to integrate their methods and solutions with the
goals and desires of all society's members. (NAE, 2008, pp. 5–6)

This fundamental lack of social and ethical concerns is especially troubling given that introductory
texts on environmental sociology or science and technology studies contain theoretical and
empirical examples of how addressing social concerns makes for better engineering. Social
ecologists (e.g., Murray Bookchin) or treadmill of production theorists (e.g., Allan Schnaiberg,
Kenneth A. Gould, or David Pellow) would remind us that resource sustainability is only possible
through political, social, and economic justice (Gould & Lewis, 2009).

Note that advocating for ethics, or even a socially-conscious engineering pedagogy, does not
necessitate an acceptance of a luddite epistemology (Winner, 1977) or an outright rejection of
solving problems with technological inventions. In fact, such an outright rejection of technology
would be no better than the determinism we are critiquing. Bookchin writes:

It is not surprising to find that the tension between promise and threat is increasingly being
resolved in favor of threat by blanket rejection of technology. To an ever-growing extent,
technology is viewed as a demon, imbued with a sinister life of its own, that is likely to
mechanize man if it fails to exterminate him. The deep pessimism this produces is often as
simple as the optimism that prevailed in earlier decades. (2004, p. 42)

To be clear, then, we are not saying that the NAE’s Grand Challenges are unimportant, or that the
application of engineering expertise is the wrong course of action for solving problems like access
to clean water. We do contend, however, that ethics and the politics of technology should feature
just as prominently and fundamentally in engineering challenges as, for example, economics.
Consider the quote from the introductory essay of the report:

Most obviously, engineering solutions must always be designed with economic
considerations in mind—for instance, despite environmental regulations, cheaper polluting
technologies often remain preferred over more expensive, clean technologies. (NAE, 2008,
p. 5)

Now, add “ethical” to “economic” and change the example accordingly:

Most obviously, engineering solutions must always be designed with both economic and
ethical considerations in mind—for instance, despite environmental regulations, cheaper
polluting technologies often remain preferred over more expensive, clean technologies.

Explicit recognition of social and environmental costs would help level the playing field among
competing technologies, while simultaneously acknowledging engineers’ ethical responsibilities to
protect people and the environment. For example, a water filtration system that makes it easy to
bottle water and sell it has different societal effects than a system that delivers potable water from
a public spigot.

In this section we have outlined our objection to the Grand Challenges report: it reinforces the
technocratic view of progress as described by Leo Marx (2006), and it fails to meaningfully consider
social and ethical concerns. Not only does this lead the authors to equate the importance of such
elite interests as “improving virtual reality” with the necessities of access to clean water, but it also
makes for bad engineering, where technology’s development trajectory is taken as given. Such
technological determinism—the assumption that technology’s development trajectory is inevitable
and, hence, not subject to human intentions—strips engineers and others of their imagination for
shaping the future in alternative ways. The next section will consider the broader cultural milieu that informs and, in turn, is shaped by the Grand Challenges report. By elaborating this cultural perspective, we hope to demonstrate what is at stake when documents such as the Grand Challenges report ignore ethics, while also revealing that the report itself is a cultural artifact.

TECHNOLOGICAL DETERMINISM DIES HARD

To their credit the Grand Challenges authors acknowledge the existence of social/ethical issues in the application of engineering solutions when they note that “many of engineering’s gifts to civilization are distributed unevenly” (NAE, 2008, p. 6). But their characterizations of such issues are oversimplified, false dichotomies of social divides (e.g., “wealth and poverty, health and sickness, food and hunger”). Such complex conditions are not binary on-off states but rather a continuum that exists both within nations and across the globe. Who goes hungry, for example, is as much a function of politics, culture, economics, and ethics as it is of agricultural production (Bijker, 2009; Winner, 1986; Woolgar & Cooper, 1999). Though Grand Challenges suggests that “engineers must frame their work with the ultimate goal of universal accessibility in mind” (NAE, 2008, p. 6), no attention is given to how engineers might go about contributing to the solution of such complex problems, other than, à la Moses, pushing forward with technological innovation.

It is worth restating that the technocratic view not held exclusively by the technological elite; it is also reinforced and constantly reinvigorated by popular cultural artifacts and events. We have already briefly mentioned the 1964 World’s Fair, which we will dive a little bit deeper into its historical significance. Then, we will move on to the importance of more recent cultural touchstones in articulating Americans’ evolving relationship to technology.

By the 1920s, the automobile had already increased the average distance between home and work in the U.S. context (Hall, 2002). The monumental changes, however, came just as America was entering World War II. Large private companies had begun buying up local rail lines and letting them go derelict, just as affordable automobiles were coming on the market. For those who could not afford these cars, buses would have to suffice. New bus lines were marketed as modern, even the wave the future, but did not offer the same reliability as fixed rail trains (Hall, 2002; Jackson, 1987). The 1939 New York World’s Fair was a prerequisite for the third fair in 1964–1965. (The first New York World’s fair was held in 1853 in what is now Bryant Park.) It was at the 1939 World’s Fair that America got its first taste of General Motors’ vision for the future. Kenneth Jackson describes General Motors’ 1939 Futurama exhibit:

Miniature superhighways with 50,000 automated cars wove past model farms en route to model cities. Five million persons peered eventually at such novelties as elevated freeways, expressway traffic moving at 100 miles per hour, and “modern and efficient city planning—breath-taking architecture—each city block a complete unit in itself [with] broad, one-way thoroughfares—space, sunshine, light, and air.” (1987, p. 248)

The models were not fantastical imaginings of a possible future. They were meant to state, with authority, that the future would look like this, and General Motors (GM) was actively working to make it happen. Such spectacular plans could only be implemented by a consortium of some of the most powerful corporations in the world. Indeed, the American Road Builders Association (ARBA), with General Motors as its largest member, lobbied Congress with huge sums of money. ARBA, by the end of World War II, “had become one of the most broad-based of all pressure groups, consisting of the oil, rubber, asphalt, and construction industries; the car dealers and renters; the trucking and bus concerns; the banks and advertising agencies that depended upon the companies involved; and labor unions” (Jackson, 1987, p. 248).
The ARBA lobby held an essay contest in 1953 on the need for better roads. The winning essay was titled “How to Plan and Pay for Better Highways.” Its author and the recipient of the $25,000 prize was none other than Robert Moses (Caro, 1974; Jackson, 1987; Samuel, 2010). Moses, as we noted above, was able to amass immense influence over private and public funds. He used his power and wealth to radically alter the New York City landscape: tearing through viable Bronx neighborhoods (Berman, 2003) and bucolic Long Island estates (Hall, 2002) with impunity.

Moses had completely transformed New York City in the intervening years between the 1939 and the 1964 World’s Fairs. He used the 1964 Fair itself as an excuse to build more highways and, as organizer of the Fair, gave preferential treatment to the car companies at the Fair by giving them seven times more space than any other vendor (Samuel, 2010). The updated 1964 Futurama exhibit was even more ornate and spectacular than the prior one. Futurama ranked as the most popular exhibit both in 1939 and in 1964, but in the latter version, the goals were bigger, further away technologically, and with larger time horizons. This future was occupied by underwater resorts, moon colonies, and deserts turned into automated farms watered by desalinated seawater. The promises of Futurama were only slightly more optimistic than those offered in the Grand Challenges report.

In an effort to keep up with GM, Ford hired Walt Disney as lead consultant for its pavilion. Disney’s participation in the show made it “inevitable that corporate America would look to Walt Disney to embed promotion of their brands within an entertainment format, that is, to cloak consumer culture as popular culture as a persuasive selling technique” (Samuel, 2010, p. 109). The 1964 World’s Fair was not the first and certainly not the last time Disney, or any other media empire, was hired to sell a product or enrich a brand. What was unique about the New York World’s Fairs was the singularly grand vision for the future that cars demanded. Futurama was meant to sell cars, certainly; but in order to assure a century of ever-expanding business, the automobile companies had to be world creators, not merely makers of cars. They built, from whole cloth, a brand new world and presented its inevitability as both apparent and objective. So as to affirm this inevitability, each participant left Futurama with a pin that read, “I have seen the future!” GM and Ford had the financial and political resources to create the vision, but it would take widespread public acceptance of that future to make the vision a reality.

Significant parallels can be drawn from how cars were sold to Americans in the 1950s and how information technologies are being sold today. GM, Ford, and Chrysler have been replaced by Apple, Microsoft, and Google as the business behemoths of North America. These are the newest world builders, and their vision is just as grand and ambitious. World building need not be as deliberate, or as conspiratorial, as ARBA’s decision to buy up streetcars and replace them with buses and cars while at the same time pressuring the federal government to spend unprecedented sums on roadway infrastructure improvements. In the case of information technologies, the technology-steeped future was illustrated by industry as well as members of the public sector. The work of making the Internet seem inevitable was just as much in the hands of WIRED Magazine gurus Kevin Kelly (2010) and Chris Anderson as it was in the hands of the U.S. National Science Foundation (NSF) and the Defense Advanced Research Projects Agency (DARPA). The institutional interweaving among industry, government, and academe has been widely covered (Collins & Evans, 2002; Etzkowitz & Leydesdorff, 2000; Kleinman & Vallas, 2001; Slaughter & Rhoades, 2009) and so we wish to take a different approach, elaborating the semiotics and cultural interchange among these broadly defined actors.
As mentioned earlier, the *Grand Challenges* report briefly diverges from its “objective” mode to cite the 2007 movie, *Live Free or Die Hard*, as a reasonable depiction of what could happen if cyber security is not taken up as one of engineering’s Grand Challenges. The Die Hard franchise is notable, among other reasons, for the variety of its source material. The first two movies were based on paperback action novels published in the mid to late 1980s (McTiernan, 1988; Harlin, 1990). The third installment, *Die Hard: With a Vengeance* (McTiernan, 1995), was adapted from an orphaned screenplay titled *Simon Says*. The fourth movie, *Live Free or Die Hard* (Wiseman, 2007), however, is a radical departure from the prior three (Banks, 2012). *Live Free* is based on a *WIRED Magazine* article, “A Farewell to Arms,” in which John Carlin describes the U.S. military’s preparations for “I-war” (Carlin, 1997). Carlin quotes the Chinese military newspaper, *Jiefangju Bao*, for a summary of I-war. It reads, in part:

> After the Gulf War, when everyone was looking forward to eternal peace, a new military revolution emerged. This revolution is essentially a transformation from the mechanized warfare of the industrial age to the information warfare of the information age. Information warfare is a war of decisions and control, a war of knowledge, and a war of intellect. The aim of information warfare will be gradually changed from “preserving oneself and wiping out the enemy” to “preserving oneself and controlling the opponent.” (1997, For a Crisp, Succinct . . . section, para. 2)

*Live Free* is about control: the control of people, resources, institutions, and (most importantly) infrastructure. The plot revolves around a spurned government cyber-security official named Thomas Gabriel (quoted at the beginning of this article), who carries out the mythical “fire sale” cyber security breach. The “fire sale” is named as such because, just like the eponymous inventory clearance event, “everything must go.” Mass media, financial systems, and infrastructure are all compromised and brought under the control of Gabriel’s small army of hackers and mercenaries. They are only able to accomplish such a feat by anonymously soliciting outside hackers to write viruses under the auspices of a corporate computer security firm. Once the viruses have been written, Gabriel orders all of the hackers killed. John McClane (played by Bruce Willis) saves one of the hackers, Matthew Farrell (played by Justin Long), just as the assassin team arrives at his apartment. The rest of the movie follows Farrell and McClane as they attempt to thwart the massive attack on America’s computer-run infrastructure.

The casting of Justin Long as an emasculated, naïve-yet-cynical computer geek—the foil to Willis’s grizzled and raw masculinity—can be read as an extended allegory for the generational tension between the millennials and the baby boomers.4 The millennial is a technological determinist, but is much more nihilistic and dystopian about what may actually come to pass. He is shot through with the cyber-libertarian ethics of hacker groups such as Anonymous and Lulsec and the millionaire playboy pirates who run his favorite torrenting sites. Technology, as it appears to Farrell, improves individuals’ lives; society is an afterthought. McClane has come to recognize that there is no technological white knight that will end hunger or disease. His technological optimism-turned pragmatic idealism is representative of his fellow baby boomers who, just as they are reaching retirement, find the social safety net in tatters. Institutions are corrupt and inept, and technology is just as alienating as it is tragically flawed. This tension is perfectly demonstrated in two scenes.

In the first scene, McClane is escorting Farrell to a police precinct just as the “Fire Sale” begins. Gabriel calls McClane and offers him a tradeoff similar to the U.S. far right’s current economic plan: sacrifice Farrell (the millennial) and McClane’s debt will be eliminated and his children will be “set

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4 Interestingly enough, these two generations are also represented by this article’s authors.
for life.” He makes this offer only after emptying McClane’s retirement fund as a demonstration of his power.\textsuperscript{5} McClane declines the offer and (by way of machine-gun-equipped black helicopter) is immediately denied by Gabriel the relative safety of his cop-filled SUV.

The second scene comes just as the full effects of the Fire Sale have become clear. Farrell, recognizing his own latent desire for wanton destruction of “the system,” prompts a frank discussion of what is at stake:

\begin{quote}
Farrell: This is virtual terrorism.
McClane: What?
Farrell: You know, first time I heard about the concept of a fire sale . . . I actually thought it would be cool if anyone ever did it. Just hit the reset button and melt the system just for fun.
McClane: Hey, it’s not a system; it’s a country. You’re talking about people, all right? A whole country full of people. Sitting at home alone scared to death in their houses, all right? So if you’re done with your little nostalgic moment and think a little bit and help me catch these guys, just help me. Just put yourself in their shoes.
\end{quote}

This exchange between McClane and Farrell mirrors the Faustian bargain demanded by \textit{Grand Challenges}: if you take any interest in these engineering “challenges” that does not conform to the grand narrative of progress (such as hitting the “reset button”), you are co-signing your fellow Americans to a short life of Hobbesian terror.\textsuperscript{6} The young radical and the skeptical citizen alike are posing a danger to everyone’s collective livelihood. Conversely, the established order should be ready to sacrifice itself for the wellbeing of the younger class of knowledge workers that (literally as well as figuratively) holds the passkeys to our digital infrastructure. The “old national faith in the advancement of technology as a basis for social progress” (L. Marx, 2006, p. 4) not only keeps McClane (and the sympathetic audience) loyal to this sociotechnical regime, but it translates a system of pipes and cables into a country.

The thread we have followed from non-fiction (\textit{WIRED} article) to fiction (\textit{Live Free or Die Hard}) and then back to non-fiction (the \textit{Grand Challenges} report) does not represent a sort of grand collusion on the scale of ARBA automobile-centered world building, but it is just as effectual. Kelly, the creator and original editor of \textit{WIRED} Magazine, has long been an evangelist for the digital future-apparent. His book, \textit{What Technology Wants} (2010), is a remarkable blend of Eastern religions, technological determinism, utopian dreaming, reflection on the Unabomber’s manifestos, and honest debate with texts like Langdon Winner’s \textit{Autonomous Technology} (1977). Kelly claims to have read “almost every book on the philosophy and theory of technology” (2010, p. 199) and yet his conclusions are morally ambivalent and rather uncritical of the effects of technology. He contends that the “technium”—the globally interconnected system of technology—acts as a counter to the natural entropy of the universe. While nature tends toward chaos and lessening diversity, the

\textsuperscript{5} This makes for an interesting comparison to \textit{With a Vengeance}, wherein an equally decade-appropriate offer is made: a dump truck full of inflation-resistant gold bullion stolen from the Federal Reserve Bank of New York (McTiernan, 1995).

\textsuperscript{6} The Enlightenment thinker, Thomas Hobbes, is most popularly known for his description of life without societal comforts: “In such condition, there is no place for Industry; because the fruit thereof is uncertain; and consequently no Culture of the Earth; no Navigation, nor use of the commodities that may be imported by Sea; no commodious Building; no Instruments of moving, and removing such things as require much force; no Knowledge of the face of the Earth; no account of Time; no Arts; no Letters; no Society; and which is worst of all, continuall feare, and danger of violent death; And the life of man, solitary, poore, nasty, brutish, and short” (1651).
technium builds complexity and order (2010). The job of humans, according to Kelly, is to nurture this superhuman force and push it toward the service of all mankind. We are in agreement with Kelly that taking an explicit and active role in shaping the path of technology is necessary, but we cannot abide the naturalistic metaphor and the sense of ever-increasing technological complexity and the control that it demands.7

Kelly can frequently be found on the lecture circuit, giving talks with titles like, “Quantifying Ourselves through Technology: How What Technology Wants Can Inform What the Healthcare Consumer Wants,” to a room full of medical-device manufactures at the “ePharma Summit” (“ePharma Summit Agenda,” 2012). This constantly revolving door of futurist authors, business leaders, tastemakers, and engineers reflect and comprise the self-reinforcing logic of technological determinism. Indeed, some of the coauthors of the Grand Challenges report work in, and have helped to create, Kelly’s world.

Kelly’s book title, What Technology Wants, is a fascinating reversal of Leo Marx’s concluding questions:

> Does improved technology mean progress? Yes, it certainly could mean just that. But only if we are willing and able to answer the next question: progress toward what? What is it that we want our new technologies to accomplish? (2006, p. 12)

Kelly, epitomizing the technocratic view, flips this logic on its head, and instead says that improved technology produces progress by its very nature:

> [W]e will generate more options, more opportunities, more connections, more diversity, more unity, more thought, more beauty, and more problems. Those add up to good, an infinite game worth playing.

> That’s what Technology wants. (2010, p. 359)

Returning to the Grand Challenges report’s silence on social and ethical concerns, we see that such considerations are a non sequitur to today’s technological determinist. We do not want to ascribe too much influence to Kelly, and we do not think we have. He is merely an easy connection to Grand Challenges—by way of WIRED and Die Hard—which is why we focused on his particular contributions to technological determinist thought. But Kelly is not alone. He is one of many technocratic boosters of the information society and all it entails (and disregards). Still, Kelly’s role is formative and hence central to the continued success of the information economy, just as the car companies were formative and central to the future of automobile culture as represented at the World’s Fairs. It is through their cheery TED Talks (Jurgenson, 2012), international consortia (Burrell, 2012), and everyday influence on individuals’ relationship to computers (Eubanks, 2011) that Kelly and his apostles frame the debate around what constitutes progress.

CONCLUSION

Here we have offered a few broad remarks on how the Grand Challenges in Engineering report contributes to and is a product of the larger cultural milieu dominated by technological determinist thinking. The report gives us a mixed bag of challenges, with economical solar energy and access to clean water side by side with such large-scale technological fixes as nuclear fusion and carbon

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7 For a full review of Kelly’s book and its dangerous political and ethical implications, we direct the reader to Evgeny Morozov’s (2011) review of What Technology Wants.
sequestration. Again, we can learn something from the book of Moses wherein large-scale technological fixes have produced social injustice and technological quagmires. The high-rise projects constructed by Moses, though intended as technological fixes for poverty, lacked the community values of the neighborhoods they replaced. As a result, drug-abuse and crime plagued many of them. And today the Cross Bronx Expressway, Moses’ technological fix for streets jammed with traffic, is itself the most congested roadway bottleneck in the nation (Dolnick, 2010). Indeed, it becomes apparent, as Langdon Winner observed, that a technocratic view can mask racist and classist political commitments and impacts (Winner, 1986).

The _Grand Challenges_ similarly does not make its political commitments and impacts transparent, and so begs us to ask what political commitments and impacts are masked by today's technocratic vocabulary. By explicitly referencing blockbuster movies like _Die Hard_, _Grand Challenges_’ authors are not-so-subtly demonstrating their symbiotic relationship with a culture industry that encourages technological determinism. Kelly and others ask that we seek out and embrace technocrats like Robert Moses (or Justin Long) rather than asking more fundamental questions about how we go about solving problems with technology. In the end, _Grand Challenges, Die Hard_, and Kelly's philosophy all say the same thing: The risks associated with complex technological systems are best mitigated by adding more technology and trusting experts implicitly.

As noted above, the _Grand Challenges_ introduction points to the importance of “public understanding of engineering.” Most efforts to increase public understanding, like the technocratic view, get it backwards. Rather than starting with the achievements of engineering—past, present, and future, marvelous though they may be—it would better serve both engineering and the public to clearly specify what the social and ethical commitments of engineering are and ought to be. From this vantage point, the challenges of engineering would be no less difficult to achieve than those put forward in _Grand Challenges_, but they would be far more likely to result in genuine social progress.

Regardless of the particular content or subject of future reports, we must also remain sensitive to the scale of perceived problems and their attendant solutions. As Allenby and Sarewitz have suggested, we should:

> Lower the amplitude and increase the frequency of decision making. Many small decisions allow much more attention to be paid to complex systems as they evolve, so that policies can track the system more easily and more consistently and so that gaps between policy and reality don’t grow dangerously large. (2011, p. 164)

Lower amplitude and increased frequency means less-grand challenges and more human problems. It means fewer grand, sweeping narratives and more contingency and reflection on the immediate past. Working and thinking at a more human scale means considering what is possible in each contingent scenario and reacting to the needs of individuals as well as real, not imagined, communities. This is a good step towards a more ethical engineering practice with a more explicit focus on social justice. It is essential, however, that such a scaling down of work is explicitly stated. Otherwise, such small endeavors look somehow less meaningful or powerful than the large, sweeping generalizations that are so maladroitly put forward in _Grand Challenges for Engineering_.

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We’ve Been Framed!  
Ends, Means, and the Ethics of the Grand(isode) Challenges

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Since the United States’ National Academy of Engineering’s Grand Challenges were first publicly articulated in 2008, engineering educators have used its ideas to motivate their work. While there is a sense of moral imperative around pursuing selected Challenges, work that critically examines the ethics of the Grand Challenges has so far been rare. In this paper, examining the process surrounding the framing of the Grand Challenges generates a series of ethical questions about both the specifics of the Challenges and the processes that gave rise to them. A Grand Challenges lesson plan for classroom implementation focuses students on the ethics of problem framing, and the consideration of social justice questions as an integral part of professional ethics.

KEYWORDS: critical pedagogy, engineering for everyone, ethics, Grand Challenges, National Academy of Engineering, problem framing, technology means and ends

INTRODUCTION

Since the National Academy of Engineering (NAE) first publicly articulated the Grand Challenges for Engineering in 2008, engineering educators in the United States have responded explicitly by creating “Grand Challenge” courses (Johnson & Siller, 2010; Ross, 2010; Savilonis, Spanagel & Wobbe, 2010) and curricula for both K–12 and undergraduate students (Bottomley, Lavelle, & Martin-Vega, 2010; Rippon & Collowfellow, 2010), and by utilizing the Grand Challenges to bolster arguments for working toward more integrated, multidisciplinary, development-and-sustainability focused approaches (Foster & Heeney, 2009; Heun & VanderLeest, 2008; White, Crawford, Wood, & Talley, 2010; Zhang, Vanasupa, Zimmerman, & Mihelcic, 2010).

For engineering educators concerned about liberal education for engineers, the Grand Challenges lend prestige and political weight to the broader efforts around multidisciplinary approaches, and around the incorporation of ecological and human welfare into engineering education. Many if not most of the Challenges (see Table 1) relate in some way to sustainability or humanitarian efforts, and most require holistic thinking that transcends the narrow traditional disciplines of engineering (NAE, 2011a).

For those interested in engineering ethics and the delivery of engineering ethics curricula, the Grand Challenges offer a rich field of proposals. While ethical questions associated with many of the

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1 Editors’ note: The capitalized, non-italicized forms of “Grand Challenges” and “Challenges” found throughout this paper refer to the broader body of work stemming from the original 2008 NAE Publication. Where the actual publication is inferred, the terms are presented in italics.
topics have been addressed elsewhere (Brown & Schmidt, 2010; Bostrom, 2003; Brey, 2009; Gardiner, Caney, & Jamieson, 2010; Goodman, 1998; Traer, 2009), the descriptions of the Challenges mostly do not include any ethical analysis, let alone from a standpoint of social justice.

This article, along with the others in this special issue, takes the risk of asking some hard questions of the Grand Challenges. Underlying the Grand Challenges project is a presumption that, having been selected, the fourteen Challenges are not only important undertakings, but also that they should go forward. But are they necessarily morally imperative? Are they necessarily for the greater good? Do they promote or hinder social justice? Ought they be undertaken at all? Such questions are a place to begin engaging the ethics of the Grand Challenges.

It may be that engineering educators are, in some sense, afraid to ask some of these questions. Many of us most likely to ask the ethical questions are also those who would advocate for the incorporation of holistic and multidisciplinary approaches to engineering. The larger project of the Grand Challenges, the discourse and buzz generated, politically moves that advocacy forward. Why risk alienating NAE members and others on the Grand Challenges committee, powerful allies in the engineering education reform effort?

As an engineering educator committed to social justice, I offer this analysis because examining the Grand Challenges in light of engineering ethics and social justice can open up a set of larger questions that move us forward in defining the parameters of purposeful and significant work for the engineering profession in society. In this sense, backers of the Grand Challenges project who are allies of engineering education reform will recognize the discussion of ethics as an invitation to a kind of reflexive practice (Finlay & Gough, 2003), deepening the conversation by reflecting critically on the Challenges and the processes that produced them.

The NAE has defined the scope of several problems that constitute the “grand” work of the profession in this century. This paper seeks to describe and analyze the Grand Challenges from a social justice perspective, posing ethics questions about the actors, the selection process and criteria, and the means and ends of the Challenges themselves:

- What does it mean to frame out a set of “Grand Challenges” in engineering? What does it say about the role of technology in society, or the role of engineering? How might other understandings about technology in society have led to different framings?
- Who participated in this framing, and by what process? Who was left out of the deliberations, or given a lesser role?
- Why are the Challenges framed as morally imperative or at least for the greater good? Should they be framed this way? Are the ends even desirable, and for whom? Why are certain technologies included, and not others?

Table 1: Fourteen “Grand Challenges” of Engineering

<table>
<thead>
<tr>
<th>Make solar energy economical</th>
<th>Provide energy from fusion</th>
<th>Develop carbon sequestration methods</th>
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<tbody>
<tr>
<td>Manage the nitrogen cycle</td>
<td>Provide access to clean water</td>
<td>Restore and improve urban infrastructure</td>
</tr>
<tr>
<td>Advance health informatics</td>
<td>Engineer better medicines</td>
<td>Reverse-engineer the brain</td>
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<tr>
<td>Prevent nuclear terror</td>
<td>Secure cyberspace</td>
<td>Enhance virtual reality</td>
</tr>
<tr>
<td>Advance personalized learning</td>
<td>Engineer the tools of scientific discovery</td>
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As an engineering educator committed to social justice, I offer this analysis because examining the Grand Challenges in light of engineering ethics and social justice can open up a set of larger questions that move us forward in defining the parameters of purposeful and significant work for the engineering profession in society.
What ethical consideration was given, or needs to now be given, to the means by which we might strive to meet such challenges?

As this paper examines these four broad areas, it produces a set of questions for further exploration in both engineering ethics and engineering studies. The paper closes with a sketch of a classroom implementation that guides students in asking similar questions of the *Grand Challenges* as they explore them topically, focusing students on the ethics of problem framing, and the consideration of social justice questions as an integral part of professional ethics.

**FRAMING**

Engineering Studies scholar Gary Downey (2005) among others has pointed out that problem framing is as important as it is neglected in engineering education. Engineers are trained not to pay attention to the underlying structures that define and shape our work. Rather we tend to concede to others the work of framing problems we solve in a "given: find" format. To put it another way, sociologist Robert Zussman in his 1985 study of engineers observed that

> The technical rationality that is the engineer's stock-in-trade requires the calculation of means for the realization of given ends. But it requires no broad insight into those ends or their consequences. Engineers are aware of, are trained to be aware of, these limitations; insofar as they do consider ends, they cease to act as engineers. (pp. 122–3)

Zussman calls out the narrow framing of engineering ethics as not concerned with the ends of one’s work. By abdicating responsibility for problem framing, engineers are allowing our work to be framed—and are potentially being set up to commit unjust acts. The title of this piece reflects the voice of engineers waking up to the realization of their involvement in an unjust project, crying “we've been framed!” never realizing that we are in fact far from innocent.

The Grand Challenges project sets forth ends for engineers, implicitly invoking moral imperatives, but never articulating an ethical argument for pursuing these ends. Here I seek to bring fundamental questions from the field of ethics, and in particular, from social justice traditions within ethics, to bear on the *Grand Challenges* in order toilluminate the ways in which power operates through the structure of the NAE, the profession, and engineering education in framing what engineering is, and what engineering can be.

It is not my intent to produce an objective or systematic analysis of the Grand Challenges, because that would require pretending that I am somehow outside or above the processes that produce such a report. As an engineer and engineering educator I am embedded in the structures of power that produced the report. Quite directly, I have served on two advisory boards to the NAE, though neither worked on the Grand Challenges. As an engineer committed to social justice, I seek to resist injustice within these structures, even as I am a part of them.

Thus my intent here is to be transparent about my own commitments and assumptions as I seek to shine the light on hidden commitments and assumptions of the Grand Challenges project. I want to understand how power works throughout the engineering profession, and my own practice is no exception. As a queer female engineering professor at a small private liberal arts college for women, I enjoy an odd mix of simultaneous dismissal and prestige from colleagues and in the profession. I am an active participant in the Engineering, Social Justice, and Peace network, whose values and commitments are out in the open and also out of the mainstream.
The method used for my analysis is document studies, a qualitative method in the frame of naturalistic inquiry (as opposed to positivist inquiry), used by (inter alia) historians to analyze primary sources (Lincoln & Guba, 1985). An idiographic description and analysis of the Grand Challenges are presented together below, organized around the four questions I posed in the introduction. These questions, grounded in the literature on engineering and social justice, reflect my own subjectivity: certain assumptions of the Challenges are visible to me and able to be questioned, while others not. Locating this piece in a special issue on the topic of the Grand Challenges allows for analysis from other vantage points that I hope, taken together, will create a more complete analysis.

I offer a particular framing of “ethics” here that reflects a movement of scholars in engineering ethics seeking to broaden the boundaries of this field. Among these scholars, Johnson and Wetmore (2007) argue for better integration of Science and Technology Studies (STS) with engineering ethics, incorporating ideas from STS like co-construction of technology and society and broadening the scope of engineering ethics beyond individual professional acts to include societal level problems. Such integration also makes possible the incorporation of critical perspectives, used throughout my analysis because of their particular relevance to social justice.

**WHO CHOSE THE CHALLENGES?**

The committee that developed the Grand Challenges comprised 18 people (12 engineers and 6 others, all in scientific fields), only three of whom were women (only one of the women was an engineer). About a third was from academia, a third from government/public service, and a third from industry, with a nearly exclusive emphasis on inventor/entrepreneur/CEOs in that sector. Some committee members had work and/or life experience outside the United States, including in Africa, Asia, Latin America, and the Middle East, but all or nearly all had strong ties to the United States, limiting the range of international perspectives privileged to inform the Grand Challenges, which are both national and global in scope. All committee members were over 35 with impressive career records, including at least 12 members of the National Academies. Data on other axes of diversity such as race and ethnicity were not available (NAE, 2011b).

Input was sought from the general public via the NAE website. The NAE boasts that over 1000 people from over 40 countries submitted comments (NAE, 2011c). However, reading the comments makes clear that the people who responded were not representative of the public at large but rather appeared to be from a relatively elite, science/technology oriented group connected in some direct or indirect way to the NAE. While the comments provided input to the Committee, it was ultimately the Committee Members who selected the Grand Challenges. Their choices were reviewed by a group of 49 reviewers; biographies are not provided in the NAE materials as they were for the Committee members, but it is worth noting that 26 of the 49 are members of the National Academies (NAE, 2011d).

Why were particular individuals chosen to participate on the Committee or as reviewers? Why were 100% of the Committee members scientists and engineers? Why were career accomplishments so central to the selection process? Does the prestige of the NAE, and of its members, lend grand-ness (or grandiosity?) to the Challenges?

At least some of the Grand Challenges relate very closely to the work of individual Committee members. For example, the emphasis on personalized medicine in "Engineer better medicines" reflects Craig Venter's interest in innovation in this area, exemplified by his controversial publication of his own genome (Levy et al., 2007). “Manage the nitrogen cycle” is a passion of Rob
Socolow, whose work is cited in the write-up (NAE, 2008, pp. 16-18). He is also deeply involved with carbon sequestration, another one of the Challenges, where his work is referenced again (NAE, 2008, pp. 13-15, 51). This raises a question about framing—why the heavy emphasis on personalized medicine in “Engineer better medicines?” Why wasn’t “Develop carbon sequestration methods” more broadly defined as addressing climate change, with a more complete range of methods to address the problem included? How were the specific climate-related challenges selected: “Provide energy from fusion;” “Make solar energy economical;” and “Develop carbon sequestration methods?” What are the assumptions—for example, about economics and the position of solar technology (it’s presently too expensive; there’s nothing wrong with our market system, we don’t need to internalize environmental externalities, there is nothing wrong with our energy policy... we just need to make it cheaper)—that go into defining and selecting a particular Challenge? Why were other energy methods (wind, hydrogen, biofuels—or for that matter, energy efficiency and conservation) left out? By what process were they eliminated?

It is not surprising that individuals on a committee would advocate for issues they are passionate about; naturally they consider the issues that have become their life’s work to be important. Thus, it is perhaps completely expected that “Engineer the tools of scientific discovery” would be a priority among a group of 100% scientists and engineers. However, this highlights the ethical importance of who participated and who did not in shaping the Challenges. What is not considered because of who was not at the table? Would a different group with different personal priorities produce different challenges? If the group were more representative of a cross-section of the profession, or of the nation as a whole, or of the global population, how would the Challenges be differently defined?

**UNDERLYING ASSUMPTIONS: TECHNOLOGY AND SOCIETY**

The framing of the Grand Challenges reflects a number of assumptions about the role of technology in society, as well as the role of engineering as a profession. Four questions are posed here in order to examine some of these assumptions.

1. *Is Engineering Grand?* First, there is the “grand” framing—engineering is being put forward as a noble profession that can address important problems of the day and of the future. This is of course a kind of self-promotion that seems perhaps more grandiose than grand. Even within the Challenges selected, engineers have played problematic roles, and are not necessarily heroes. For example, engineers are given a role here to “Prevent nuclear terror;” but no mention is made of engineers’ role in inventing nuclear terror in the first place (Norris, 2002). The argument for “Advance health informatics” is in part to respond to attacks from biological and chemical weapons—never mind U.S. engineers’ role in advancing the state of the art in production and delivery (Cirincione, Wolfthal, & Rajkumar, 2005). The argument could be made that engineers’ involvement in developing these horrors increases our responsibility now to rise to the Grand Challenges—but such an argument is nowhere in evidence. It would require a certain level of humility and frank discussion that falls outside the current framing.

2. *Is High-tech Always Better than Low-tech?* The Grand Challenges are future-oriented and emphasize innovation and development of new solutions that feature high technology. There is little place for “mundane science” here (Kammen & Dove, 1997). For example, in addressing the world’s need for clean water, the discussion emphasizes high-tech solutions such as nanofiltration and desalination (NAE, 2008, pp. 19-21) over widely available low-tech solutions such as filtration with local materials (Colwell et al., 2003).
3. Is Technology Always Progress? Innovation is presented as progress, and there is no hesitation around the introduction of new technologies in pursuit of the Grand Challenges. As noted above, existing technology is passed over for the shiny new high-tech thing. Embedded in this notion of progress is an assumption of technological determinism, that “Throughout human history, engineering has driven the advance of civilization” (NAE, 2008, p. 1). In this one-way trajectory, technology pushes history forward. An alternative view would be the idea of co-construction of technology and society (Taylor, 1995), in which social developments might emerge along with engineering developments, each influencing and giving rise to the other. Thus, we must not only ask about “ethical implications” of the Grand Challenges, as if technology drives or creates the need for ethics in a one-way relationship. We must also ask about the ethics of circumstances that give rise to the Challenges: at what point in history does the project emerge, in what country with what geopolitical agendas, with what kind of engineering workforce positioned how within the society? (Johnson & Wetmore, 2007).

4. Is Technology an End in Itself? The uneven framing of the various Grand Challenges raises the question of purpose. Are some Challenges merely about demonstrating technological prowess, while others are directed toward solving a larger social problem or meeting humanitarian needs? The challenge to “Make solar energy economical” is extremely specific, and involves multiple goals: saving money/making the technology affordable, developing improved materials for energy capture and storage, meeting people’s energy needs, and meeting larger sustainability goals. The criterion of affordability is not applied to fusion, the other energy technology whose development is a Grand Challenge; why is this value applied to one technology and not another? When a Grand Challenge presents technology as solving complex problems such as access to clean water, or meeting a need for “better medicines,” it raises the question of whether these are at their core technological problems. Is it genetic technologies and personalized therapies that will improve medicine the most, or might we need to focus on changing economic, political, and social values to expand access and provide basic care to all?

ENDS: SHOULD WE UNDERTAKE THE GRAND CHALLENGES?

Among the unasked questions regarding the ethics of the Grand Challenges is whether undertaking these challenges would be ethical in the first place, as well as whether these ought to be the highest priority efforts for the profession in society.

In the discussion of the Challenge to “Reverse-engineer the brain,” the primary justification for this undertaking is improving artificial intelligence (AI) (NAE, 2008, pp. 34-36). Is this desirable? Who benefits? What are the risks, and who bears the costs? A side benefit (to the main goal of improving AI) is the ability to address “brain disorders,” though no critical thought is given to the social dynamics and power relations by which some ways of thinking are labeled “disordered” (Foucault, 2006). An understanding of these power relations might give us pause, asking again which brain “disorders” are to be cured, and who decides?

Finally it is pointed out that artificially intelligent brain implants could (among other things) help “crippled people to walk” (NAE, 2008, p. 34). The use of the word crippled is frankly shocking as it has been considered pejorative in the United States for decades. Both the use of the term and the suggestion that these brain implants are the “solution” to a “problem” of impairment disregards the social model of disability (Davis, 1996) which defines disability as a form of social oppression. One manifestation of this oppression is readily evident when infrastructure does not accommodate all people’s forms of mobility, but rather limits access to enforce a particular norm (e.g., walking) and
demands conformity to it (in this case, by going to the lengths of reverse-engineering the brain). From this perspective, “Universal design” might be a more socially just Grand Challenge.

Similarly, “Advance personalized learning” advocates for electronic delivery of learning without acknowledgment of the arguments put forth in response to the development of distance learning, of what is lost both in interpersonal interaction and in the corporatization and privatization of learning (Lieberwitz, 2002). An apparently un-ironic reference to The Matrix holds up Trinity’s “downloading” into her brain a learning module on how to fly a helicopter as an ideal to be attained (Silver, 1999). However, considering the larger context of the film and its themes, this entire Grand Challenge is clearly problematic; Trinity and her colleagues are, after all, imprisoned in a virtual reality, and their goal is to resist the Artificially Intelligent machines that control their bodies and minds (Haslam, 2005).

What does the choice of certain ends imply about the means? Langdon Winner (1986) has identified the centralized power structures required for the development of nuclear power (which would extend here to fusion technologies). Who will be able to participate in the engineering projects identified, and in what capacities—as embedded corporate workers, as government employees, as contractors, as non-profit employees, or as independent professionals? Will engineers have autonomy to control the means of production? What latitude will they have to negotiate the ethical boundaries of a project? Some of these questions relate directly to the means, discussed further below, but to what extent does the shaping of the ends constrain the means?

MEANS: HOW SHOULD WE DEFINE AND PURSUE THE CHALLENGES?

Some Grand Challenges represent ends that are unlikely to be opposed by many—who wouldn’t want to increase people’s access to clean water, or prevent nuclear annihilation? However, what it means to achieve these goals and how one goes about achieving them raise important ethical questions that are largely unaddressed in the NAE’s descriptions of the Challenges.

For example, the discussion of “Restore and improve urban infrastructure” highlights energy and environmental considerations as well as aesthetics, but does not consider the potential for these projects to displace populations with low social capital. Affordability of housing after improvements and linkages between infrastructure improvements and gentrification are not addressed. Whether a particular project to rebuild infrastructure can be considered ethical depends critically on careful attention to how vulnerable populations are affected, and whether and how they are able to participate meaningfully in the process so as to reap the project’s potential benefits (NAE, 2008, pp. 22-24).

The description for “Engineer better medicines” briefly acknowledges ethical problems with privacy and affordability of personalized medicine. “Of course, a transition to personalized medicine is not without its social and ethical problems. Even if the technical challenges can be met, there are issues of privacy when unveiling a person’s unique biological profile, and there will likely still be masses of people throughout the world unable to access its benefits deep into the century” (NAE, 2008, p. 32).

Why aren’t privacy and access issues incorporated into the Challenge’s framing? If a broader notion of “better” medicines were considered, one might, for example, include the problem of multinational corporations patenting indigenous medical knowledge, or “orphan” drugs that have been or could be developed by pharmaceutical companies, but investment is discontinued when it is clear that the drugs will not be profitable because a disease primarily affects poor people (Stix,
2004). Thus, “Engineer better medicines” may be a worthy challenge, but how one goes about doing so, (and how one defines better, and for whom) matters.

The discussion of access to clean water begins to acknowledge that the core problem may not be technological, mentioning that “In many instances, political and economic barriers prevent access to water even in areas where it is otherwise available” (NAE, 2008, p. 19). However, this realization does not alter the problem framing or cause the Committee to reconsider the strong focus on desalination and nanofiltration. The problem is seen to be not at the level of problem definition, or even technological development, but at the level of implementation: “Even within a given country, clean, cheap water may be available to the rich while the poor have to seek out supplies, at higher costs, from intermediary providers or unsafe natural sources. Technological solutions to the world’s water problems must be implemented within systems that recognize and address these inequities” (NAE, 2008, p. 21).

But this raises key questions—if the problem is political and economic, is the solution technological? If inequity is to be addressed, shouldn’t engineers play a strong role in refusing water privatization schemes and other inequitable processes? Shouldn’t current engineers involved in water privatization, dams that displace the poor, and other projects be called out as less than grand? The means by which engineers deliver clean water matters immensely. These important ethical issues are not discussed in the Challenge description beyond the text already quoted here. Indeed, Zussman (1985) would argue that in order to be considered members of a profession, engineers must recognize their responsibility extends beyond the technical and take up these questions addressing both the means and ends of our professional practice.

Finally the Grand Challenge of “Prevent nuclear terror” is curiously framed. In the wake of the dropping of the bombs on Hiroshima and Nagasaki, many recognized these events as acts of terror, because the bombs killed civilians living in areas that were not militarily significant in order to send a political message to others unaffected (Zinn, 1995). While any use of nuclear weapons can reasonably be considered terrorism by this definition (state terror if acted out by governmental authorities), the NAE’s framing sees only those acting outside of governmental authority as “terrorists” to be deprived of nuclear weaponry. The means of “Prevent nuclear terror” include securing nuclear materials, surveillance of nuclear activity, deactivating bombs, and, oddly, two activities that are not preventive at all (cleanup/public communication and determining who was responsible) (NAE, 2008, pp. 37-39). This is a most unfortunate framing, as efforts for peace are not in the picture at all, even though building international and intercultural understanding has the potential to eliminate the need for nuclear weapons in the first place. Improving international or interpersonal relations can reduce the likelihood that authorized or unauthorized development and/or use of nuclear weapons would ever be considered worthwhile (and would likely also alter the language and framing of “nuclear terror”). George Catalano’s (2004) call to engineers to contemplative action for peace would, in my view, constitute a Grander Challenge, more difficult yet morally transformative.

**Taking These Questions into the Classroom: Lesson Plan**

Here I provide a lesson plan for an introductory engineering course that includes both intended majors and non-majors. It could be adapted for other course contexts, both in terms of class content and classroom size.
Background Information on Class/Students

The course in which this lesson has been offered, “Engineering for Everyone” is a design-based introduction to engineering in which students work in groups on a hands-on semester-long design project. Topics for the project vary from year to year, but the course in which the lesson plan was implemented focused on the world's water problems, and students designed and built drinking water purification systems, with particular attention to difference, power, and privilege operating in global development settings. The class had 22 students, with about half intending to major in engineering, and half taking the class for fun and exposure to a different discipline at a small private liberal arts college. Most were first-year students, but some were sophomores, juniors, and even seniors, with the upper-class students most likely to be majoring outside of engineering. The class met for 80 minute classes twice a week and one weekly three-hour hands-on session set aside for group meetings, lab, or shop work. Students meet for 80 minute classes with one longer hands-on session each week set aside for group and lab or shop work. The Grand Challenges assignment is one of three essay assignments that address the social context of engineering; the others are a narrative of how an individual student sees their own values and goals fitting with the world of engineering, and an analysis of how technology and society are co-constructed, examining the case of a technology of their choice.

My overall pedagogical orientation is toward critical (feminist, anti-racist) pedagogies (Darder, Baltodano, & Torres, 2008). In this setting of a course designed collectively by our faculty with shared responsibility for teaching, my practices align well with mainstream active learning approaches, but also include critical engagement with issues of power and privilege. Here the Grand Challenges unit is designed to help students critically question power relations in the field of engineering and in the production of the Grand Challenges themselves, asking whether the Challenges themselves and the means of the achieving them are socially just.

Objectives

The purposes of the Grand Challenges unit are to:

1) Familiarize students with the National Academy of Engineering and the aspirational Grand Challenges report as a means of understanding the profession.
2) Realize the importance of problem framing in engineering by critically examining the Grand Challenges as pre-framed problems.
3) Discover, Challenge, and Re-Imagine ways that engineering might be involved in addressing critical social and ecological problems.
4) Apply ethical frameworks to the broad social contexts in which engineers operate.

Student Preparation

Students explore the NAE website as their reading before class. It is a fully developed and rich source of information on the Grand Challenges. Students can also be assigned an additional background reading on engineering ethics that covers different values and principles that can be applied in analyzing ethics problems, or that material can be delivered in class. Reading questions that provide accountability for student reading include: “Explain the social and historical context of the NAE report. Who is the NAE, and what are they saying about engineering in the United States and in the world through this report?” and “What is the difference between consequentialist and deontological ethics?”
Class Activity

1. Think Pair Share: (Students think to themselves about the questions for a moment, talk with a neighbor for a few minutes, and then pairs volunteer to share what they discussed.) What is the NAE and what does it do? Why do you think the NAE did a project called “Grand Challenges”? How might the project have been different if the challenges didn’t have to be “grand”?

2. Large Group Discussion: Who decided what the Grand Challenges were? Do you think it would have been different if other groups of people were asked to decide what would be the important work of engineers in society? Who else might they have asked?

3. Role Play: Assign groups to represent different segments of society who were left out of framing the Grand Challenges. Brainstorm 3 challenges the group would most like to see addressed in the world. What can engineering do to address these challenges?

4. Large Group Discussion: How to approach problems in engineering ethics. Beginning with an example such as “Is it ethical to pick up a pine cone in a State Park?” or “Is it ethical to pick up money on the sidewalk?” students can learn to transform a gut answer into a formal ethical argument. Pushing students to articulate why they answer the way they do and identifying key values or principles they are applying to their case (e.g., “thou shalt not steal” or “the greatest good for the greatest number”) helps them to understand how to analyze problems in ethics. Encourage them to think critically about what conditions or facts are most relevant to the situation (how much money is it? What species of pine?), and might affect their approach to the problem. Explain or have them read about the differences among consequentialist, deontological, virtue, and other types of ethical approaches. I find it useful to explain the categories first and then introduce flexibility by illustrating how ethicists might blend them or depart from them.

Homework: Essay

Choose one of the Grand Challenges as defined by the NAE, and provide an ethical analysis along one of the following two lines:

a) Whether or not the Challenge should be pursued.

b) How the challenge should be pursued. Are there ways to go about it that would be more ethical, or less ethical/unethical? Why? For whom?

Consider ethical arguments and counterarguments. Focus not so much on whether but why an action is ethical or unethical. Utilize different ethical frames of argument—ones that consider consequences, ones that consider duties, rights, or responsibilities, ones that consider values or virtues, etc.

Evaluation Rubric for Homework

The descriptions below refer to the highest achievable score of 4 points for each item. Descriptions for 3, 2, and 1 point are not included here for length but can be used to clarify expectations for evaluation.

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WRITING QUALITY - Writing is clear, concise, and logical, with sufficient detail, free from casual language, grammatical errors and awkward sentence construction. Words are used correctly. Superfluous information omitted. Essay is well-structured with a clear introduction, development of thesis with supporting statements, and recapitulation that summarizes the main arguments. Document is professional in appearance, follows specified length guidelines, etc.

ARGUMENTATION - Sources are cited in APA format, including course readings and ethical frameworks used. Sources appropriately and sufficiently support argument. Support is specific and precise. Critical thinking is evident in consideration of multiple ethical frameworks and stakeholder perspectives. Counterarguments are anticipated and addressed. Statements are consistent within the context of the essay, without logical flaws. Avoids universalizing and oversimplification. Argument progresses logically and sequentially. Argument is persuasive and compelling. Argument demonstrates familiarity with the Grand Challenges and an understanding of how problem framing shapes the engineering profession.

ETHICS - Applicable moral concepts, rules, and principles are identified. Multiple ethical frames are applied correctly. The locus of disagreement is named, and facts and concepts brought to bear upon all possible resolutions. Alternative resolutions are considered where facts and concepts may change. Student provides evidence of deep reflection and iterative thinking about the Grand Challenges, including creative thought about how engineering can address critical social and ecological problems (with or without the Challenges).

Discussion
In a more expanded unit, or in a class where students are not familiar with ethics, students could ask people they know from different parts of their lives (technical and non-technical, peers and family, etc.) what they think the biggest challenges are for society…. And which ones do they think are ones that engineers or technology could help address.

These activities focus students on the ethics of problem framing (who wins and who loses when you choose one framing over another?), and on the consideration of larger social justice questions as an integral part of professional ethics as engineers. It raises early questions about process and inclusion as well as outcomes for different individuals or groups. The Grand Challenges are made to intersect with deep questions about technology in society, and in doing so students critically question a nationally authoritative body in the profession.

Instructor Self-Evaluation
This lesson plan was offered in spring 2012 to 22 students at Smith College. Two end-of-semester surveys and one mid-semester focus group conducted by an outside staff person asked students open-ended questions about the course (all variations on what is working well, and what would you change). In all three assessments, students spoke positively of “how she brings social justice and ethics to the forefront of our discussions of engineering.” At the end of the semester ethics was the second-most frequently mentioned thing students thought worked well in the class (after the hands-on project). Students asked for clearer instructions on the essays in all three assessments, and one student wanted to make the essays more relevant to course material, while another asked for “less ethics.” On balance, this was a successful assignment, though it can be modified in the future to clarify expectations for the assignment and strengthen its relevance to the course project. Because the course topic was the world’s water problems, the connection to “Provide access to clean water” may have been clear, but not the connection to other Challenges. In any case, better
communication around the connection between the Challenges essay assignment and the course theme should be sufficient to address this concern.

**CONCLUSION**

This inquiry has produced a number of questions for engineering ethics and engineering studies scholars to pursue further, and a lesson plan for teaching the Grand Challenges that focuses students on the ethics of problem framing, and the consideration of social justice questions as an integral part of professional ethics. Ultimately both pursuits question whether it is appropriate for the profession's priorities or for engineering education's priorities to be driven by the Grand Challenges project (to the extent that it is), or by other similar reports by authoritative bodies.

At a minimum, a less grandiose and more humble approach for the National Academies to take in the future would invite epistemologies and knowledges outside of engineering, including Science and Technology Studies, which has much to offer engineers’ understanding of the role of technology in society. To further social justice goals, the processes that produce and disseminate these reports ought to become more democratic, more responsive and accountable to non-engineers in society, and more critically reflexive. Whether engineers and engineering educators concerned about social justice pay attention to these reports in the future may depend upon their ability to do just that.

**REFERENCES**


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ARTICLE

The Unbalanced Equation: Technical Opportunities and Social Barriers in the NAE Grand Challenges and Beyond

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The US National Academy of Engineering’s 2008 report, Grand Challenges for Engineering, puts forward a provocative vision of future civilization and engineering’s role in it. Notably, the report signals a trend in engineering toward more explicit and direct engagement with enduring, complex social problems, offering intriguing opportunities for exploring the relationship between engineering and questions of social justice. This paper makes one such exploration by analyzing the report’s explicit framings of engineering-for-social-problem-solving and the implicit assumptions underlying such framings. It shows how the report frames the non-technical factors as external to—and often barriers for—engineering. In contrast, technical challenges, even immense ones, are framed as wholly within engineering’s dominion and as opportunities for both engineering and human civilization as a whole. The paper argues that Grand Challenges signals contemporary tensions in the profession as it seeks an expansive domain of influence and relevance while at the same time narrowly circumscribing what engineers should be accountable for knowing and doing.

KEYWORDS: boundary work, Grand Challenges, interdisciplinary collaboration, National Academy of Engineering, sociotechnical practice, technical-social division, textual analysis

INTRODUCTION

In 2008, the US National Academy of Engineering (NAE) released its report, Grand Challenges for Engineering, which describes 14 major engineering challenges that must be overcome to make the world “a more sustainable, safe, healthy, and joyous—in other words, better—place” (p. 6). These challenges encompass areas as diverse as energy, the environment, infrastructure, human health, security, learning, and research, but in each case the emphasis is on what are articulated as the “engineering” dimensions of the larger problem domain and, in particular, on the technologies and tools that might enable solutions to evident, often enduring challenges facing contemporary civilization.

Since its publication, the report has drawn significant attention from the engineering community and has been the subject of two national summits, Obama Administration initiatives, and STEM education programs, both K–12 and university.1 Industry leaders also have been eager to

1 The second national NAE Grand Challenges Summit was held in Los Angeles, 6–8 October 2010. The White House Office of Science and Technology Policy and the National Economic Council announced a request for information on Grand Challenges on 21 September 2009. NAE Grand Challenge K12 Partners Program was launched “[t]o create an awareness of and involvement in the NAE Grand Challenges for the K12 community.” A number of universities have joined the NAE Grand Challenge Scholars Program to prepare the next generation of engineers for solving grand-challenge problems.
demonstrate the connection between their activities and the grand challenges, such as IBM’s Big Green Initiative, which claims to address a number of challenges identified in the NAE report.2

Given this attention, and the general enthusiasm with which it has been received, the NAE Grand Challenges for Engineering report (hereafter Grand Challenges) offers an intriguing opportunity to reflect on how engineers imagine what engineering is and what its proper role in society ought to be, including how it relates with questions of social justice. This paper contributes one such reflection, carefully analyzing Grand Challenges as a way to interrogate broader social and cultural meanings surrounding engineering, technology, and their relationships to major social and environmental problems. We argue that, in important respects, Grand Challenges relies on a problematic and increasingly outdated understanding of engineering as distinct and apart from the social contexts in which it is practiced. In other words, the report endorses a conception of engineering that is “purely technical” at its foundation. As we will show, this conception undermines the goal of shifting engineering, as a whole, toward social problem solving by misconstruing critical attributes of both the social problems being addressed and the technologies intended to solve them.3

Certainly, we are sympathetic to the impulse underlying the report, namely to direct engineering energies toward “the century's great challenges” (p. 6), with the derivative social-justice goals of addressing the needs of the impoverished, ameliorating ecological decay, and enhancing the ability of people everywhere to participate meaningfully in social life. Despite these sympathies, our analysis identifies key assumptions embedded in Grand Challenges that are likely to constrain efforts to develop robust solutions to complex social problems in ways that enhance social justice.

In this paper, our approach to social justice follows a body of emerging literature on engineering and social justice (Baillie, 2006; Catalano, 2007; Leydens, Lucena, & Schneider, 2012; Riley, 2008). To advance social justice through engineering, we emphasize two dimensions of engineering competency that combine ethical stances and cognitive capabilities. The first dimension involves comprehension of the broad (social) context of engineering work and candid reflection on the role of engineering and engineers in social change (Jamison, Christensen, & Botin 2011). The second dimension calls for engineers’ critical engagement with political forces in order to advance the interests of marginalized social groups through collaborative sociotechnical action (Downey, 2009). We argue that maintaining a social-technical dichotomy in engineering thinking—as evident throughout Grand Challenges—impairs engineers' ability to engage the contextual complexities impinging on their work and, further, alienates non-engineering stakeholders with whom engineers ought to be collaborating.

In identifying and describing problematic approaches taken in Grand Challenges, our purpose is not merely to offer a detached, academic critique. Instead, we are motivated by a desire to reframe

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2 To see how industry leaders discuss grand challenges as business opportunities, see the blog entry “You need to think of each of these grand challenges as a business.”

3 Various facets of the social/technical divide in engineering have been extensively examined in engineering studies. Faulkner (2000) inquires into the gendered nature of the social-technical dualism in engineering. Lagesen and Sørensen (2009) suggest two sets of reasons for the continuous maintenance of the social/technical binary in engineering: one represents the attempt of retaining the “scientific” nature of engineering knowledge while it addresses social issues; the other stems from engineers’ justification of its professional privilege. Cech and Waidzunas (2011) suggest the social/technical dualism excuses engineers from discussing hard social problems within the profession. Our analysis of the social/technical divide in the Grand Challenges report intends to reveal a gap between engineers' attempt to maintain professional privilege and the practical needs of fully addressing social challenges.
“engineering” in ways that make it more amenable to social problem solving and to help engineering decision makers more productively engage the various social forces influencing their work. Hence, after working through some of the most problematic assumptions and approaches evident in *Grand Challenges*, we then propose alternative understandings of engineering that are more in line with the complexities of the grand-challenge problems and that more readily align with social justice initiatives. These alternative understandings synthesize insights being developed within the engineering studies community—and within science and technology studies (STS) more broadly—over the past few decades. In our assessment, these understandings promise more imaginative engineering approaches and more robust contributions to social justice.

**METHODOLOGY**

The paper is based on a textual analysis of *Grand Challenges* in light of recent work in engineering studies and STS. Our approach “views texts as symbolic action, or means to frame a situation, define it, grant it meaning, and mobilize appropriate responses to it” (Manning & Cullum-Swan, 1994, p. 465). We focus attention on how and where the authors of the report demarcate “engineering” from that which is external to engineering but which engineers must respond to nevertheless. In particular, we investigate how the authors characterize engineering activities and knowledge versus how they characterize those forces impinging upon engineering from the outside. As indicated above, we take the report as representative of one dominant way engineering and its relationships to its various (social) contexts are understood, both inside and outside the engineering community; however, we do not include those larger contexts in our analysis.5 Because the empirical material and our institutional home situate this analysis in the US, our arguments apply particularly to the US context. Nevertheless, we hope and expect many of the insights gained apply elsewhere as well. While *Grand Challenges* provides the primary empirical material of our analysis, we also draw comparisons between *Grand Challenges* and the prior NAE report, *The Engineer of 2020* (2004).

By “textual analysis” of *Grand Challenges*, we refer to an interpretative method that explores the rhetorical and conceptual terrain of the report text itself as opposed to how meaning making around the report varies in specific social contexts. Our process entailed four basic steps:

1) Close reading of the report;
2) Identification of sentences and phrases that address the engineering/non-engineering boundary or engineering’s relationship to non-engineering factors, including various dimensions of social-problem solving;
3) Coding of the text using categories that spanned and connected these articulations; and
4) Iterating the categorization scheme to create a delimited set of themes that captured most of the identified articulations.

The first three steps were carried out independently and in parallel by each of the authors, and the fourth step was carried out in collaboration, in part by merging our individual findings. After

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4 In STS, the practice of negotiating what is inside and what is outside a given category is called *boundary work*. See Geiryn (1983) for a classic analysis of how scientists demarcate science from non-science.

5 We acknowledge the limitations of our approach in that the content of *Grand Challenges* is a social production derived from particular social and organizational arrangements and inflected by strategic goals, which we do not systematically explore. Yet, insofar as the *Grand Challenges* report is the authors’ articulation of how engineering *ought to be*, and not simply a transparent statement of what it *is*, there is value in characterizing and unpacking the idealized vision of engineering as portrayed therein.

6 We did not deliberately follow any particular textual analysis method (e.g., Foucaultian discourse analysis, Saussurian semiotics), but our analysis was framed by a social-constructivist framework and theoretical insights from STS and Engineering Studies around boundary work and the technical-social binary.
refining our themes, we referred to The Engineer of 2020 to clarify and highlight alternative articulations about engineering and its context, and how these alternatives might offer a more promising vision for reorienting engineering to grand-challenge problem solving and social justice.

The Grand Challenges text is significant and deserving of systematic attention for two reasons. First, it resonates strongly with participants in engineering, engineering policy making, and engineering education as evidenced by its uptake, dissemination, and frequent referencing in these communities. The approach taken in Grand Challenges clearly aligns with the perspective taken by a wide and influential audience interested in engineering, education, and their reform. Second, the report’s authors disproportionately represent corporate and research institutions (numbering 15, with 3 exceptions—one journalist, one politician, and one development banker), suggesting that it provides mostly an “internalist” account of engineering. As an internalist account, the perspective provided is from that of (particularly situated) practicing engineers and emphasis is placed on the variables within those persons’ primary domain of influence. Given this perspective, perhaps it is not surprising to see a more-or-less neat demarcation between technical opportunities and social barriers; however, this neat demarcation makes challenging the assumptions underlying it even more important to explore. Hence, while the scope of our empirical material is narrow, we believe the implications of our analysis are broad.

“ENGINEERING” IN GRAND CHALLENGES: THE TECHNICAL-SOCIAL DIVIDE

The Grand Challenges report puts forward an image of engineering that is gallant, perhaps even heroic. The report opens: “Throughout human history, engineering has driven the advance of civilization” (NAE, 2008, 1). It later adds that engineering brings together “the rules of reason, the findings of science, the aesthetics of art, and the spark of creative imagination” and has “revolutionized and improved virtually every aspect of human life” (p. 2). The veracity of such generalized claims is impossible to determine, and, besides, this particular vision of engineering serves in the report mostly as a set-up for the big challenges ahead. Nevertheless, from its first sentence, Grand Challenges frames engineering as a domain of achievement and mastery, as having tried-and-true techniques for solving big problems, and as already ready for the challenges ahead. Perhaps not surprising in a report of this type, Grand Challenges also characterizes engineering in a way that may be inspiring for the uninitiated but is otherwise problematic. The boundary between engineering and other disciplinary or professional realms is inconsistently applied and strategically played across the report. Grand Challenges identifies humanity’s great achievements as engineering achievements, even where the connection is tenuous (e.g., the taming of fire. p. 2). At the same time, it leaves totally unaddressed engineering’s contributions to social and ecological problems, including its contributions to some of the central problems underlying the grand challenges themselves.

After surveying great achievements of engineering, the report continues: “For all of these [engineering] advances, though, the century ahead poses challenges as formidable as any from millennia past” (p. 2). It then goes on to frame those problems as inevitable byproducts of civilization’s progress (e.g., caused by population growth, consumer demand, etc.) rather than unintended consequences of intended human actions—including engineering problem solving. For example, as the report celebrates engineering’s contribution to agriculture, it is silent about engineering’s contribution to creating the synthetic fertilizers that disrupt the natural nitrogen cycle. As the report salutes the great achievement of the automobile, it is silent about automobiles’ contribution to the grand challenges associated with excessive energy consumption and urban
congestion. Even the grand-challenge problems of controlling carbon emissions and preventing nuclear terror are disassociated from their engineering origins.

In a similar vein, Grand Challenges is silent about the need to anticipate unintended consequences of the technological solutions proposed for the 14 grand challenges identified. For example, the report claims that providing energy from fusion has a lot of advantages, including its inherent safety (unlike with fission, run-away reactions are not possible with fusion). Other reasonable safety concerns—like waste management and effluents⁷—are left unaddressed. Hence, the report ignores unintended negative consequences of engineering solutions in the past as well as the future.

We draw attention to these silences in the report not to suggest that the solution paths identified by the Grand Challenges authors are inappropriate, but instead to highlight the double standard applied to social and technical facets of engineering throughout the report: While engineering is cast as responsible for advancing civilization (a social phenomenon, to be sure), it is not also seen to be responsible for any ills resulting from engineered systems. While engineers should be prideful of the social benefits of the technologies they collectively have devised, there is no need, implied by the report, to hold engineering accountable for the social detriments of those very same technologies. Far from being part of the problem, a “technocratic” approach to engineering remains our best solution.⁸

Although the report’s authors claim not to have endorsed any particular approach to addressing the grand challenges identified, in fact a very particular approach to problem solving is offered. This approach takes existing engineering problem-solving techniques as sufficient (if not inevitable); it subsumes all the good associated with technological advance under “engineering” and externalizes or ignores the bad; and it puts forward narrowly technical solution paths to the complex social problems underlying each of the grand challenges. By reducing complex social phenomena to narrow technical problems amenable to traditional engineering training, Grand Challenges limits engineers’ responsibilities to their existing, narrow technical expertise. Simultaneously, the report externalizes responsibility for the (“social”) barriers that prevent or slow the creation of engineering solutions. This understanding of engineering—as merely offering tools that others misuse—is historically dominant to be sure, connected centrally to the mainstay argument that technology is neutral (Pitt, 1999). But as with the neutrality argument, the dominance of the Grand Challenges approach to engineering does not mean it is inevitable or even desirable.⁹

The Grand Challenges report’s asymmetrical treatment of technology—with the benefits of technology attributed to engineering and the liabilities to other factors—reflects a crucial assumption that carries across the report, namely, that technology challenges can be neatly separated into technical and social factors. Technical factors include various means of increasing efficiencies, refining processes, and facilitating basic scientific research. Such means, the report implies, are the best (perhaps the only) way engineers might go about addressing grand-challenge problems. Just as engineering is understood narrowly around technical factors, so too are broader

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⁷ Studies have shown that dust particles in nuclear fusion may pose a safety threat (Sharpe, Petti, & Bartels, 2002; Winter 2000).
⁸ Put simply, technocracy represents a decision-making process that prioritizes narrow technical criteria, and hence technical experts, in pursuing social goals. Early work on technocracy is Veblen (1921). Layton (1986) and Akin (1977), among others, have examined the history of technocratic movements in the US.
⁹ Social scientists in general, and STS scholars in particular, have contended the belief that technology is neutral. They have shown that some technological developments necessarily call for engineers’ value choices and their usage is inextricably entwined with certain patterns of political arrangement (Winner, 1988).
social factors understood (narrowly) as external to, but impinging on, engineering. Such an understanding is conveyed in this telling claim: “governmental and institutional, political and economic, and personal and social barriers will repeatedly arise to impede the pursuit of solutions to problems” (NAE, 2008, p. 6). With the occasional exception of economic factors (particularly, costs), Grand Challenges articulates organizational, political, and cultural factors both as outside engineering and as “barriers” to be overcome wherever they exist in tension with achieving narrowly specified technical goals.

Defining Engineering as Technical Problem Solving

The technical-social division is especially problematic in how Grand Challenges translates complex sociotechnical challenges into narrowly technical challenges and then suggests that existing technologies or engineering developments currently on the horizon are capable of solving these technical challenges. An example of such a reductive interpretation of grand challenges is the discussion about personal learning. The report starts by drawing attention to individual differences in learning and stating that existing educational approaches lack flexibility in meeting individual needs. While this set-up hints at the importance of addressing different learning styles, personalities, motivations, and so on—in other words, looking at the full complexity of the challenge of individualized education—the report then turns abruptly toward a specific, narrow technical sub-problem: optimizing learning outcomes by manipulating the sequence in which materials are presented to students. To achieve this radically narrowed goal, the report introduces a solution: a computer algorithm that “eliminates unsuccessful presentation sequences and modifies successful ones for a new round of tests, in which the least successful are again eliminated and the best are modified once more” (NAE, 2008, p. 46).

As most thoughtful educators recognize, sequencing of material is a minor variable in the larger equation of successful (individualized) learning. What material is included, how materials are connected to students’ existing knowledge and experiences, and the dynamics of the learning environment are all widely recognized as more significant than the ordering of content alone.10 As with most other examples, the particular solution offered and the (radically) narrowed technical problem it “solves” are perfectly acceptable as far as they go, but they do not go far enough. Individual learning differences demand attention to a wide set of pedagogical and curricular variables, and devising solutions to this larger problem requires both an appreciation of the problem’s complexity as well as an understanding that optimizing any given approach does not substitute for the arguably more important judgment about what approach ought to be used to begin with.

Extending from the theme of social justice are questions surrounding the purpose and roles of education and the institutional and economic contexts in which education takes place. Without considering the “higher purposes” of education, for example, the report says nothing about how the computerized learning model proposed might facilitate critical thinking, commitment to the educational process, empathy for others, lifelong learning, or student ability to identify and solve problems for themselves. The report is also silent about structural problems surrounding the current American educational system in particular, such as the lack of qualified and dedicated teachers, the under-representation of minority groups in higher education, waning interest in STEM

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10 See, e.g., Eberly Center for Teaching Excellence’s “Teaching Principles.” Also see Freire’s (1996) classical work on the power dynamics of education. Psychological literature on college students’ epistemological development also stresses the importance of metacognition in learning (Baxter Magolda, 1992; Belenky, Clinchy, Goldberger, & Tarule, 1986; Hofer & Pintrich, 2002; King & Kitchener, 1994; Perry, 1970).
fields, etc. By abstracting the proposed technical solution from the larger social context of education, *Grand Challenges* identifies one potentially relevant research agenda, certainly, but not one that addresses anywhere near the complexity of the initially stated problem.

By stripping away the social and political context of big social problems, *Grand Challenges* not only oversimplifies the nature of the challenges; it also fails to encourage engineers to assume prominent roles in collaborations initiated outside narrow technical realms. The report’s approach to the challenge of providing clean water and basic sanitation in developing countries showcases such a miss. Whereas water is a scarce resource in many places in the developing world, the problems of consistent supply of clean water and sanitation services raise much broader questions than water purification or desalination systems alone can answer. Questions about infrastructure installation, health-care management, public investment, and ownership and use rights surrounding water resources are all essential components of the water and sanitation problems faced by poor communities globally (Gopakumar, 2010). To be fair, the report does recognize political and economic facets of the challenge of water provision, such as the prevalence of inequities in distributing water resources. Yet it limits the engineering-relevant focus to desalination, distillation, and purification technologies alone.

The solar energy challenge is another example of where the report reduces a complex and largely uncertain problem (making solar energy systems affordable) into specific technical indexes. In this example, *Grand Challenges* implies the necessary techniques are already in hand; the need is merely to continue refining (and ramping up investment in) developments already well along. The report discusses in detail the prospect for new technologies’ increased efficiency in transferring solar energy to usable forms, as if promising solutions to the solar challenge merely await technical implementation. Despite the report’s emphasis on efficiency in this section, the connotation of the term “efficiency” here is vague and mercurial. The report discusses, in turn, the energy conversion efficiency of commercial solar cells, the theoretical maximum efficiency of current standard cells, new materials and experimental cells, and the theoretical efficiency of yet-to-be-deployed nanocrystal-based systems. Apart from these imagined theoretical data, the report does not explain the net-gains of each solar energy project, the overall costs per unit energy generation and delivery, or the political landscape that shapes America’s renewables energy policy (e.g., Obama Administration support for such policies on the affirmative side and fossil-fuel lobbyists on the negative).

Clearly, we question the sensibility and viability of delimiting engineering along technical dimensions alone. That said, we do not question the sensibility or viability of narrowly technical expertise within engineering. To the contrary, we believe narrowly technical skills are both essential and essentially desirable, but only so in a broader understanding of engineering that spans both technical and social domains.

**The Role of Non-Technical Participants in Grand-Challenge Problem Solving**

The translation of complex sociotechnical challenges into narrow technical ones has implications for how engineers understand their relationships with other stakeholders. *Grand Challenges* extends its conceptual separation of technical and social factors to the division of labor between engineers and other practitioners. Engineers (along with scientists) are put forward as ideal role models for advancing grand-challenge solutions; other social and professional groups are frequently cast as impediments, either resistant to or not adequately supporting the technical

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11 Maria Klawe identifies these same problems in a [recent talk](#) given at the 2010 NAE Grand Challenges National Summit.
solutions offered by engineers. The role of participants outside of technoscientific disciplines, according to the approach taken in *Grand Challenges*, is merely to facilitate scientific and technical progress. The report occasionally recognizes the necessity of engineers communicating with non-engineering groups in dealing with the non-technical aspects of engineering problem solving, but that is only to facilitate or otherwise enable technical research and development. Ultimately, it is engineers who possess the requisite technical expertise. Therefore, it is they who should play the primary role in tackling the grand challenges.

*Grand Challenges* characterizes the role to be played by non-engineers as one of deference. The report highlights that the public image of engineering is not always congruent with engineers’ self-understanding, and it attributes the incongruence to public ignorance of engineering and inappropriate if not irrational resistance to technological innovation. An implicit agenda of *Grand Challenges* seems to be enhancing the authority of engineers, increasing trust in engineering, and developing within society-at-large “an appreciation of the ways that scientists and engineers acquire the knowledge and tools required to meet society’s needs” (NAE, 2008, p. 5). As the report states in its introduction:

The ultimate users of engineering's products are people with individual and personal concerns, and in many cases, resistance to new ways of doing things will have to be overcome. Teachers must revamp their curricula and teaching styles to benefit from electronic methods of personalized learning. Doctors and hospital personnel will have to alter their methods to make use of health informatics systems and implement personalized medicine. New systems for drug regulation and approval will be needed when medicines are designed for small numbers of individuals rather than patient populations as a whole. (NAE, 2008, p. 5)

In each of these cases, the new technologies are assumed to be superior to existing approaches and to be linchpins in addressing the underlying (social) problem. Non-technical practitioners in each domain are cast not as collaborators in problem solving or even as resources to be drawn on by engineers, but merely as potential nodes of resistance.12

The ideal relationship between engineers and scientists is more ambiguous in *Grand Challenges*. On one hand, engineers frequently legitimize their expertise with the authority of scientific knowledge, or even view engineering as “applied science” (Kline, 1995). Hence, scientists are viewed as natural allies. At the beginning of the report, the authors characterize engineering as “[a]pplying the rules of reason, the findings of science, the aesthetics of art, and the spark of creative imagination” (NAE, 2008, p. 2). But throughout the report, engineers are paired regularly only with scientists: “In the century ahead, engineers will continue to be partners with scientists in the great quest for understanding many unanswered questions of nature” (p. 48). On the other hand, *Grand Challenges* distinguishes engineers’ unique contributions to society, even in the domain of scientific knowledge production: “In the popular mind, scientists and engineers have distinct job descriptions. Scientists explore, experiment, and discover; engineers create, design, and build. But in truth, the distinction is blurry, and engineers participate in the scientific process of discovery in many ways” (p. 48). Here again, the report plays the boundaries of engineering loosely, in this case the boundary between science and engineering, to cast engineering in its most favorable light.13

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12 Engineers’ distrust of the public has a long history, with evidence dating back at least to the technocracy movement of the early 1900s. At that time, technocrats—many of whom were engineers—typically framed the public as a barrier to the social realignments demanded by technical rationality (Akin 1977).

13 Some engineers have argued that engineering is an autonomous body of knowledge independent of science (Vincenti, 1990).
The tension created by engineers’ ambiguous relationship with scientists represents an opportunity for engineers to embrace more collaborative and interdisciplinary inquiry into ever-more complicated sociotechnical challenges. As engineers seek to expand their roles in what are traditionally considered arenas for scientists, architects, doctors, educators, or even policy makers, they are bound to question and redefine the scope of engineering as an enterprise, and *Grand Challenges* offers opportunities for engineering to be understood in a way that includes factors beyond the technical. For example, the report repeatedly points out that contextual matters (e.g., the material, political, or organizational infrastructure surrounding water and sanitation solutions or computer security protocols) are important in specifying technical solutions. The report also occasionally emphasizes that synergy across a number of interconnected fields is needed to tackle certain types of challenges, but even here the emphasis is placed on technoscientific dimensions of problems. For example, the report suggests that personalized medicine “will be addressed by the collaborative efforts of researchers from many disciplines, from geneticists to clinical specialists to engineers” (NAE, 2008, p. 31). These openings point the way toward a more expansive understanding of engineering and its potential contributions to grand-challenge problems, but the report does not follow through with such an approach.

**ALTERNATIVE FRAMINGS: BEYOND THE SOCIAL-TECHNICAL DIVIDE**

Contrary to the approach taken in *Grand Challenges*, we argue that effectively responding to the social injustices surrounding grand-challenge problems requires rethinking engineering—both what it is understood to be and how it is practiced. This section draws on an additional NAE publication, *The Engineer of 2020*, in an effort to identify understandings to engineering that do not rely so heavily on the problematic assumptions described above.

Instead of unquestioned confidence in the sufficiency of current or emerging technologies in responding to grand challenges, we argue that acknowledging uncertainties is an essential starting point. Such uncertainties exist both with our understandings of the problems being addressed and with the engineering solutions to be applied. *The Engineer of 2020* adopted such a stance in stating: “The particular factors that will dominate engineering practice and require reform of engineering education are not predictable” (NAE, 2004, p. 59). According to this vision of an uncertain future, conventional problem-solving techniques may well be inadequate for tackling the intricate challenges facing humanity today. Additionally, some of the problems that will confront engineers in the future are certain to be unknown in the present. A more realistic alternative for mapping out the future is to admit that neither engineers nor others can be certain about the variables that will shape the future and to focus instead on developing strategies for coping with uncertainties.14 Nowhere in *Grand Challenges* do we see a call for engineers to direct their energy towards better monitoring of current “solutions” or on-going analysis of grand-challenge-type problems as they arise and evolve. In what is perhaps an ironic twist, the idealized narrowly-technical approach to engineering offered by *Grand Challenges* would be incapable even of adequately discerning the problems put forward by the report as grand challenges, given that they arise and exist beyond the boundaries of technical engineering.

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14 Science and technology policy scholars have advocated shifting away from approaches that attempt to eliminate uncertainties through systematic analysis and toward approaches that accept uncertainty in scientific and technological outcomes as inevitable. According to this approach, effort should be directed at identifying strategies for coping with unintended outcomes as they come to light over time (Lindblom & Woodhouse, 1993, Ch 2; Woodhouse & Nieusma, 2001).
In comparison to *Grand Challenges*, *The Engineer of 2020* seeks to explore new roles of engineering and engineers in a changed context. As an entry point, *The Engineer of 2020* identifies one unchanged feature of what is otherwise an ever-changing future: the interconnection between engineering and society. It states, “The future is uncertain. However, one thing is clear: engineering will not operate in a vacuum separate from society in 2020 any more than it does now” (NAE, 2004, p. 27). The remainder of this section explores three dimensions of this enduring feature of engineering by elaborating ways engineering knowledge and practice are inevitably entwined with “the social.” First, we consider the marginalization of the social in engineering and offer a more integrated model. Then, we look at engineering practice and how engineers might be more productive (in terms of grand-challenge problem solving) by collaborating on more diverse teams. Third, we propose a more reflective and critical stance toward engineering by engineers in order to promote a more realistic and balanced appreciation for what can and cannot be achieved under the model of engineering put forward in *Grand Challenges*.

**Engineering as Sociotechnical Practice**

*The Engineer of 2020* takes a decidedly different stance than *Grand Challenges* on the relationship between the technical and social dimensions of engineering. Rather than considering political, organizational, and cultural concerns as external or barriers to approaching important engineering challenges, it sees these as always existing alongside technical dimensions of engineering practice. According to the report, “it is not just the nature of a narrow technical challenge but the legal, market, political, etc., landscape and constraints that will characterize the way the challenge is addressed” (NAE, 2004, p. 35). As a result, confronting complex engineering challenges, such as updating and securing information and communication infrastructure, as suggested by the report, “will clearly involve legal, regulatory, economic, business, and social considerations” (p. 20). It is worth noting that, according to *The Engineer of 2020*, social considerations are not simply minor variables that happen to intersect with engineering practice. Rather, “consideration of social issues is central to engineering” (p. 27). In this understanding, engineering is “sociotechnical” practice, where social and technical dimensions interpenetrate through and through.

*The Engineer of 2020* does not suggest that this integrated approach to engineering should be created from whole cloth. Because engineers are comfortable with “systems analysis,” the report urges them to extend the scope of the “systems” they already consider within their domain, specifically by including facets of social systems alongside the technical. To do this, engineers will have to enrich their existing expertise with better understandings of public policy and community needs as well as enhanced social and political acumen. While experts in other domains undoubtedly have roles to play in fleshing out our understandings of sociotechnical systems, engineers share responsibility for integrating diverse insights into a coherent model. They also share responsibility for, ultimately, achieving synergy between technical and social dimensions of any given system. Such a reorientation would be beneficial for many domains of engineering practice, but it is absolutely necessary if engineering is to take seriously social injustices and their underlying causes, including those of the sort identified in *Grand Challenges*.

Better integration of the social and technical facets of engineering is one way to improve grand-challenge problem solving, but engineers might also bring themselves more fully into traditionally “non-engineering” domains as well. For example, engineers need not assume policy-making is external to their work, but instead might take an active role in engineering-related policy making, analyzing the public gains and losses of their projects, collaborating with a range of stakeholders in

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15 Thomas Hughes (1983) has famously applied such an approach in analyzing the historical development of electric power systems in the United States.
establishing promising policy directions, and otherwise providing input to the political process. *Grand Challenges* laments the existence of not-always-favorable political environments, implying engineers’ involvement in politics and policy making is a necessary evil. *The Engineer of 2020*, on the other hand, sees politics as part and parcel of engineering. As the report suggests, “the engineers of 2020 will be actively involved in political and community arenas” (NAE, 2004, p. 44). While not sole crusaders speaking “truth to power,” responsibilities for mobilizing political interests and building the political resolve needed to advance socially beneficial engineering projects fall on engineers as much as anyone. So too do responsibilities for the negative consequences of technology (that is, sociotechnical) innovation. Hence, engineering should be held accountable for devising precautionary measures with both technical and political components.

As with politics, engineering would be better situated to address grand-challenge problems if engineers did not take as “given” or fixed the apparent public demand for particular engineering solutions. What is demanded by consumers and society—as well as what is understood to be desirable, or even viable—is contingent on a range of factors, some of which engineers could take responsibility for redirecting. *Grand Challenges* offers a glimpse at such a strategy by advocating systems “designed to be compatible with human users,” but then reveals the ultimate goal of this approach is “ensuring user cooperation with new technology” (NAE, 2008, p. 5). A more productive approach to the user-technology relationship would be to ensure new technologies cooperate with their users or, more precisely, that new technologies are perceived to be worthy of accommodation by users and not imposed upon them. For example, rather than forcing teachers to “revamp their curricula and teaching styles to benefit from electronic methods of personalized learning” (as quoted above), personalized learning technologies should be developed and deployed in ways that integrate with existing curricula and pedagogies, both of which have been refined over millennia and which form the foundation of teachers’ expertise. Ignoring that foundation, and placing the burden of accommodation on teachers, follows a logic of “technology fix” in education that harkens back to well-documented failures of information-technology-driven educational reforms of the 1980s and 1990s (Pflaum, 2004).

In this reframing, the onus is placed on the designers of the new technologies that are inserted into people’s lives, rather than the other way around. This does not mean that user-resistance should halt promising new initiatives, but that such initiatives need to be made more salable to their intended audiences—and engineers share responsibility for making this happen. Extending this line of reasoning, engineers might do better in addressing grand-challenge problems by questioning existing market demand as the final arbiter of which projects get done. Instead, engineers could take market conditions as part of their domain of influence—not only identifying market opportunities and constraints and accepting them as fixed, but leveraging alternative institutions (e.g., politics, the media, education, and marketing) where existing market demand is inadequate. Consumer product innovators redirect market demand continually; grand-challenge problem solvers ought to consider the same. Recognizing limitations of the market in directing technology development toward social-problem solving is central to reconfiguring engineering in a way that makes it more responsive to social injustices.

**A Multiple-Stakeholders Model of Collaboration**

Determining new roles for engineers in the future relies on serious and sustained communication between engineering and non-engineering groups. Again, this is explicitly recognized by *The Engineer of 2020*, which notes “it is important to engage all segments of the population in a vigorous discussion of the roles of engineers and engineering and to establish high aspirations for engineers that reflect a shared vision of the future” (NAE, 2004, p. 48). It is untenable to assume engineers can
or should develop technological solutions to social problems independently of professionals and social groups with other expertise and perspectives. Real-world problems know no disciplinary boundaries: technical, financial, political, and cultural components intertwine. While professional grandstanding may serve in a limited way to advance engineering’s public image, romanticizing engineering as the “driver of civilization” probably undermines its credibility among thoughtful observers. Instead of defining themselves as apart from (and by implication above) other professional groups, engineers would do better to articulate a future for the profession that prioritizes collaboration with social/professional groups beyond research scientists—policy makers, business leaders, social scientists, humanists, users, and a wide range of others.

Our proposed model of collaboration does not entail engineers merely departing their knowledge to others—providing the technical input upon which others will draw. It requires engineers to reformulate their role in response to dynamic, sometimes unpredictable, interdisciplinary problem-solving contexts. The Engineer of 2020 recognizes that to “build a clear image of [their] new roles,” engineers will have to “accommodate innovative developments from nonengineering fields” (NAE, 2004, p. 5). That means “engineering” itself should be open to change through the process of interdisciplinary collaboration with other professional groups. This approach applies equally to engineering’s relationship to the larger public, which again diverges from what is evident in Grand Challenges. The Engineer of 2020 identifies “excellence in communication (with technical and public audiences)” as “essential attributes” for future engineers (p. 35). Effective communication skills are surely needed to better educate the public concerning engineering principles and possibilities, but good communication is always a two-way street: Engineers should conceive of the public in a way that offers potential for learning and not only teaching (or preaching) about what engineering has to offer.16, 17

Engineering, Warts and All

As mentioned above, Grand Challenges fails to acknowledge engineering’s responsibility for contributing to grand-challenge-type problems, and it does so in two ways. First, the report attributes the causes of grand-challenge problems to non-technical factors, keeping silent about the roles played by technologies in creating or exacerbating the problems. Second, because the report implies engineering is responsible only for the technical dimensions of technology making, it immunizes engineers from accountability for the non-technical causes of grand-challenge problems, even where technologies enable or exacerbate these causes. This logic parallels the decontextualized view of technology—and by implication engineers—as neutral participants in problem solving. Taken at face value, such a view would logically prevent engineers from assuming any significant role in social problem solving, since the non-technical dimensions that direct (neutral) engineering would necessarily be rendered irrelevant to how engineering was applied. Only by reversing this logic—and reflecting on engineering’s liabilities in producing sociotechnical challenges—can engineering be cast in a way that is more than tangentially relevant to the tackling of these challenges.

16 A third NAE report, Educating the Engineer of 2020, falls short of our suggestion that collaboration is a two-way street. As with Grand Challenges, Educating the Engineer implies that the primary goal of engineers improving communication with the public is “enhancing public awareness of engineering” (NAE, 2005, 27).
17 A vast body of literature in “public understanding of science”—and a journal by the same name—has developed over the past three decades. This literature emphasizes the embedded intelligence of local communities’ knowledge systems, working as they do from different perspectives and responding to different sets of variables and assumptions than outside experts.

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Unlike *Grand Challenges*, *The Engineer of 2020* frankly admits that, in addition to its benefits, “there have also been negative results of technology” (NAE, 2004, p. 48). That recognition directs attention to the question, “How can engineers best be educated to be leaders, able to balance the gains afforded by new technologies with the vulnerabilities created by their byproducts without compromising the well-being of society and humanity?” (p. 2). However unlikely it may be that the authors of *Grand Challenges* would disagree with such a statement, the report nevertheless systematically avoids recognition of any such tradeoffs surrounding technology or, for that matter, engineering. In our assessment, taking responsibility for negative consequences caused by prior technologies does not harm engineering’s credibility. To the contrary, recognizing the mixed consequences of technological endeavors benefits the profession by helping to set more realistic goals when addressing complex problems and by reminding engineers (and others) of the need for caution, precautions, and humility.

**CONCLUSION**

We share the enthusiasm of many engineers and engineering educators in redirecting engineering energies toward grand-challenge problems. But we also see these problems as an opportunity to rethink the nature of engineering and recast the relationship between engineering and society in a way more likely to respond effectively to social injustices. A textual analysis of the *Grand Challenges for Engineering* report shows that it advances a problematic and increasingly outdated image of engineering as separated from other domains of social practice and innovation. This paper has identified several of the assumptions underlying that image and described how they are untenable in understanding engineering generally, but are especially problematic if we are systematically to redirect engineering toward complex social problem solving in ways that enhance social justice. We have also identified how the technical-social dichotomy, in concert with externalization of responsibility for understanding social dimensions of technology, has problematic implications for engineers’ collaboration with non-technical participants in social problem solving. Drawing examples from *The Engineer of 2020*, we proposed alternative understandings of engineering and its proper role in identifying and solving sociotechnical problems.

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18 The implications of our analysis for engineering education are immense, spanning everything from curriculum design and accreditation practices to educational cultures in engineering to strategies for attracting prospective students into engineering programs. While beyond the scope of the present paper, this domain deserves systematic attention on its own, especially given the extent to which the *Grand Challenges* report and approach have been adopted by engineering programs.


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ARTICLE

Listening to the Quiet Voices:
Unlocking the Heart of Engineering Grand Challenges

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According to the National Academy of Engineering, the list for the Grand Challenges for Engineering are:
(1) Make solar energy economical; (2) Provide energy from fusion; (3) Develop carbon sequestration methods; (4) Manage the nitrogen cycle; (5) Provide access to clean water; (6) Restore and improve urban infrastructure; (7) Advance health informatics; (8) Engineer better medicines; (9) Reverse-engineer the brain; (10) Prevent nuclear terror; (11) Secure cyberspace; (12) Enhance virtual reality; (13) Advance personalized learning; and (14) Engineer the tools of scientific discovery. Surely, it may be difficult to find many who would find any reason to disagree with the identification of any of these topics for both the present and future engineers. Rather than object to what is included, I would like to raise the issue of what has been neglected in this list and far too often in engineering—listening to the quiet voices that speak from within each of us from our heart. I am suggesting the act of listening as one additional entry for this most important list.

In my view, one set of skills that our profession does not encourage very well is stopping and listening—stopping and listening to each other, stopping and listening to life around us, or stopping and listening even to ourselves. This is a skill that, given the pace of our modern society, technological advances and our cultural conditioning, must be cultivated for it likely will simply either never develop or quickly wither away. The question at hand then becomes how does one cultivate the ability to stop and to listen? The present work offers one such path though clearly there are countless others.

KEYWORDS: contemplative pedagogy, Grand Challenges, listening, mindfulness

INTRODUCTION

The National Academy of Engineering published its Grand Challenges for Engineering in 2008. The challenges ranged from making solar energy economical to providing access to clean water to re-engineering the brain, to list just a few. Surely, it may be difficult to find many who would find reason to disagree with the identification of any of these topics for both present and future engineers. I would like to raise the issue of what has been neglected in the Grand Challenges for Engineering and far too often in engineering generally—listening to the quiet voices that speak from within each of us, from our heart. I am suggesting the act of listening as one additional entry for the Grand Challenges.

In my view, our profession does not encourage stopping and listening to each other, to life around us or even to ourselves. An obvious question in response is to ask, “why is listening so important?” I will argue in this essay that listening is an important aspect of learning and it is a skill which we neglect at our own peril! Listening, given the pace of our modern society, technological advances and our cultural conditioning, must be cultivated, for it surely will either develop and become
stronger or quickly wither away, and eventually disappear. The question at hand then becomes, “how might we cultivate the ability to stop and to listen?” The present work offers a description of one such path, though clearly there are countless others. The path chosen is one based upon an adaptation of a contemplative pedagogy.

In a 1993 talk at Berea College, Parker Palmer pointed out that “every way of knowing becomes a way of living, every epistemology becomes an ethic.” He argued that the current epistemology has spawned an associated ethic of violence. Surely, science (and engineering) has brought enormous advances, but we cannot turn away from the central fact that the modern emphasis on objectification predisposes us to an instrumental and manipulative way of being in the world. As Palmer suggested, knowing does, indeed, grow into a way of living. The implications of this position are important in light of our work as engineers. It is not calling for a rollback of science and engineering, but rather a resituating of them within a greater vision of what knowing and living are really all about. That re-imagination of knowing could have deep consequences for education, consequences that give a prominent place to contemplative pedagogies.

Ultimately the question becomes, “what is the necessary business of education in general and engineering education specifically?” Postman and Weingartner offer the following set of questions and ideas:

[Is it] to create eager consumers? To transmit the dead ideas, values, metaphors and information of three minutes ago? To create smoothly functioning bureaucrats? These aims are truly subversive as they undermine our chances of survival . . . we would like to see the schools go into the anti-entropy business. Now that is subversive, too. But the purpose is to subvert attitudes and beliefs and assumptions that foster chaos and uselessness. (1969, p. 15)

Perhaps stopping and listening may offer engineering a way out of the instrumental and manipulative way of being in the world. I am reminded of the words of Chief Dan George:

One thing to remember is to talk to the animals. If you do, they will talk back to you. But if you don't talk to the animals, they won't talk back to you, then you won't understand, and when you don't understand you will fear and when you fear you will destroy the animals, and if you destroy the animals, you will destroy yourself. (Levey & Levey, 1998, p. 266)

These kinds of exchanges take time and reflection and point to a need for our profession to slow down and to listen much more deliberatively than we have in the past, or we run the risk of destroying our very planet.

**CONTEMPLATIVE PEDAGOGY AND LEARNING TO LISTEN**

One approach to developing the ability to slow down and to listen can be found in what is referred to as contemplative pedagogy. One of the most powerful transformative interventions developed by humanity is contemplative practice or meditation (Hart, 2004). It has been specifically designed to move human cognition from a view of reality of separateness and dualism to one in which the interconnectedness of reality is directly perceived. Contemplative practice works on the human psyche to shape attention into a far supplier instrument, one that can appreciate a wide range of worldviews and even sustain the paradoxes of life, ultimately drawing life’s complexity into a gentle, non-judgmental awareness.
Educators at hundreds of North American universities and colleges are increasingly appreciating the usefulness of secular contemplative practice (Zajonc, 2006). At conferences and summer schools at Columbia University, Amherst College and elsewhere, for example, professors have gathered to share their experiences in the emerging area of contemplative pedagogy. Their efforts range from simple silence at the start of class to exercises that school attention; and most recently, to innovative contemplative practices that relate directly to course content.

Jon Kabat-Zinn (2005) has spoken about the unification of knowing through contemplation, reminding us both how available mindfulness is, but also how difficult it can be to bring full awareness to the entirety of life. According to Zajonc (2005), the curricula offered by our institutions of higher education have largely neglected this central, if profoundly difficult task of learning to love, which is also the task of learning to live in true peace and harmony with others and with nature, which I believe is our ultimate responsibility in engineering. He adds,

We are well-practiced at educating the mind for critical reasoning, critical writing, and critical speaking, as well as for scientific and quantitative analysis. But is this sufficient? In a world beset with conflicts, internal as well as external, isn't it of equal if not greater importance to balance the sharpening of our intellects with the systematic cultivation of our hearts? Do not the issues of social justice, the environment, and peace education all demand greater attention and a more central place in our universities and colleges? (Zajonc, 2005)

Marilyn Nelson (2005) has relayed the story of teaching silence to those whose lives take them into war and conflict. Nelson added that contemplative pedagogy does not involve teaching a technique. Rather, it is teaching an “attitude [of openness to explore] the several ways in which listening can occur and how one can listen for and to silence.”

Contemplative practices quiet the mind in order to cultivate a personal capacity for deep concentration and insight. Examples of contemplative practice include not only sitting in silence but also many forms of single-minded concentration including meditation, contemplative prayer, mindful walking, focused experiences in nature, yoga and other contemporary physical or artistic practices. The concept of contemplative practice is as old as the world’s religions. Every major religious tradition includes forms of contemplative practice, such as prayer, meditation, and silent time in nature. Many practices remain rooted in their religions, and others have grown in secular settings.

**A COMPLEMENTARY PARADIGM OF STUDY: CONTEMPLATIVE INQUIRY**

One example of a contemplative practice is contemplative inquiry. Zajonc suggests the practice of contemplative inquiry as an essential modality of study complementary to the dominant analytic methods now practiced in every field (Palmer & Zajonc, 2010). Zajonc further argues that “such inquiry is at the true heart of higher education” and is an expression of the “epistemology of love” wherein epistemology refers to a theory of knowledge or, in other words, how we know what we know. To describe the method of contemplative inquiry, Zajonc delineates seven stages in this epistemology (see Figure 1).

In the first stage, respect, we may ask if in fact we respect the integrity of the subject of our study. Do we respect the other, be it a river, the Earth’s atmosphere or oceans, our employers, our clients, the societies and cultures which our technological advances impact? Rilke (2002) suggested that when we truly respect the other, we “border and protect them” as we seek to know and understand them better. I wonder in engineering how often we introduce this concept of respect into our classrooms. Perhaps in engineering design we might, but rarely in other engineering courses.
Gentleness, or according to Goethe (1994), “gentle empiricism,” lies in stark contrast to the scientific method of the Age of Science or Enlightenment. Rather than Bacon’s instruction of “putting nature on the rack,” gentleness suggests approaching the object of our attention without distortion. I would argue that seeing without distortion offers a much greater insight into what lies before us. Intimacy, the third stage, calls upon us to forgo the notion of disengaged science for the sake of objectivity but rather to approach the object of our attention with delicateness and respect. As quantum mechanics suggests, the notion of separateness of subject and object is misleading at best. According to Palmer and Zajonc, “We can still retain clarity and balanced judgment close-up if we remember to exercise restraint and gentleness” (2010, p. 95). Vulnerability challenges us to put aside a dominating arrogance and to learn to be comfortable with not knowing, with uncertainty and with ambiguity. Being able to deal with uncertainty and ambiguity is at the very heart of what, for example, accrediting organizations in engineering are requiring for tomorrow’s engineers. Participation asks us to join with the other while maintaining full awareness and clarity of mind, or in Emerson’s words, “the intellect being where and what it sees” (2000, p. 298). Transformation requires that we are transformed by the experience, that is, what was outside is now inside. We are shaped or developed or sculpted by the experience. Imaginative insight can be once again described most eloquently by Goethe (1994) who likened imaginative insight to the formation of a new organ: “Every object well-contemplated opens a new organ of perception in us.”
APPLICATION TO ENGINEERING SCIENCE COURSE:
FLUID MECHANICS OF LIVING SYSTEMS

As an illustrative example, the method of contemplative inquiry is developed for an undergraduate engineering course in fluid mechanics in our bioengineering program. From the outset, students may be told that the fluids course is going to be taught using a different paradigm than perhaps they had experienced previously in engineering. The ultimate goal for the course is given to them as the development of that imaginative insight, that quality of understanding that describes the “creative insight which every scientist, scholar, and artist recognizes as the axis around which their work turns but which cannot be produced on demand” (Palmer & Zajonc, 2010, p. 96). This insight then is the ultimate reasoning for listening. That is all that may be offered about this mysterious goal though it can again be brought back to their attention throughout the semester.

The writing strategies Nelson (2005) utilized in the course she taught at the United States Military Academy at West Point included: “journaling, which focuses and complements the meditation experience; free-writing, which comes close to recording ‘inner speech’; and clustering, which taps into the creative, intuitive, right-brain function that lies at the core of meditation.” Each of these strategies are adapted for the bioengineering fluids course. A regular class session includes five minutes of meditation at the beginning of each class meeting; fifteen minutes of daily meditation outside of class; journaling; and various writing exercises. Each class period begins and ends with a moment of quiet contemplation. Various techniques included my simply standing quietly in front of the classroom to the recitation of a mantra to a ringing of a bell and a calling for undivided attention to some object at the front of the room. I muse about how much easier my teachers had it in my high school—a Roman Catholic college preparatory school taught by strict Christian Brothers in long, flowing and intimidating black robes! There, each class hour started with an invocation to the divine mystery and a remembrance of the patron saint of that particular order.

My intention is to begin with a meditative practice borrowing from the practice of yoga. The immediate response is likely to be a combination of shock, disbelief and laughter but gradually as each day passes, my hope and suspicion is that the immediate reaction will be slowly replaced by many more thoughtful looks and much less time passing before quiet and order are present.

Insight, also referred to as Vipassana meditation, is a simple form of Buddhist meditation that calms and concentrates the mind (Rosenberg, 2004). The practice originated with the Buddha over 2,500 years ago. In the form offered here, the practice starts with learning to keep one’s attention on the breath. This is a form of concentration practice. The course progresses through mindfulness practices, such as noticing the body, the feelings, one’s thoughts and one’s life patterns. As the practice continues, one learns to be more present in the moment.

This practice is a meditation practice and not a religious system of belief. As an introduction for students to the practice of meditation, five different techniques are presented, as outlined by Fleischman (1999):

- Mindfulness of breathing
- Mindfulness of the body
- Mindfulness of feelings
- Mindfulness of the mind
- Mindfulness of patterns
These different techniques are to be presented during the first five weeks of the class. Subsequently, students will be asked to meditate upon the following subject matter, each of some considerable relevance to the course.

As the course is focused upon the flow of fluids, it is easy to make connections among the flows in pipes as observed by Reynolds in 1895, the flow of oxygen in our respiratory systems including our lungs as well as the lungs of other living animals, and the flow of blood in our arteries and our veins as well as those same flows in other living creatures (Vogel, 1997). Further, similar analytical ideas will be extended to the flow of sap in trees. Students will be asked then to meditate on the flow of air in their respiratory systems, the flow of blood in their cardiovascular systems and the slow movement of sap in the majestic sugar maple trees that inhabit the northeast region of the United States.

After some preliminary development in class, we shall focus upon the lift and drag characteristics of single birds and migratory flocks of birds discussing similarities and differences between the low speed aerodynamics of our technological world to that of the natural world (Alexander, 2004; Vogel, 1997). Students will be asked then to meditate on the migrations that occur throughout the year as native birds deal with the changing weather patterns we experience throughout the year.

Comparisons between laminar fluid mechanics and turbulent fluid mechanics will be made. The closure problem and its implications in engineering will be considered. Focus will be placed on the uncertainty that surrounds turbulent flow fields such as those encountered in the flow of blood in the human heart. Somewhat unexpectedly, the lack of turbulence in the heart indicates a weakened heart in a seriously weakened condition. Students will be asked then to meditate on the flow of blood in their bodies both through the pumping action of the heart and the cleansing action of the kidneys.

Emphasis will be placed upon how accounting and conservation equations are used to derive familiar laws, such as Kirchhoff’s current and voltage laws, Newton’s laws of motions, Bernoulli’s equation and others (Berger, 1996). Extensive examples that span the breadth of modern bioengineering, including physiology, biochemistry, tissue engineering, biotechnology and instrumentation shall each be a focus of a weekly meditation. As an example, the birth rate, death rate and the movement of a species into and out of a sanctuary such as the wolves at Isle Royale can be considered (Peterson, 1995).

**PROPOSED RESEARCH OUTLINE**

The research question for this particular effort is the following: “Do students develop a deeper understanding of the course material when presented concepts in an environment incorporating a contemplative pedagogy?”

In response to the proposed integration of meditation and other contemplative activities into the course, a socio-cultural theory offered by Cole and Engstrom (1993) shall be used as the theoretical framework for the study. Vygotsky (1978) conceived socio-cultural theory in the early 1920’s. It emphasizes the central role of social relationships and culturally constructed artifacts in organizing thinking. It attempts to theorize and provide methodological tools for investigating higher cognitive processes by which social, cultural and historical factors shape human functioning. Cole and Engstrom’s model provides several dimensions along which one can study the classroom as an activity system. They identify factors, other than the subject matter or students or teachers, which...
must be taken into account when trying to understand how knowledge is distributed within a system. These factors include the curriculum, language use, rules and community.

A mixed methods approach will be taken in assessing the results (Johnson & Onwuegbuzie, 2004). This approach involves the collection and/or analysis of both quantitative and qualitative data, which seems particularly relevant for the proposed work. A key feature of mixed methods research is its methodological pluralism or eclecticism, which frequently results in superior research (compared to mono-method research).

**Final Thoughts**

Let me attempt to tie the proposed course and its teaching back to the *Grand Challenges for Engineering* as described by the National Academy. The Academy states in its Grand Challenge Scholars Declaration of Principles:

The profession of engineering has been, true to its Latin root *ingeniare*, about invention. For the past one hundred years, about as long as most college of engineering programs have existed, the list of the most important engineering achievements is dominated by devices: planes and spacecraft, cars and agricultural machines, lasers and PET scanners, to name a few from the National Academy of Engineering report of the last century. Almost a decade into the new century, another NAE committee has addressed the new engineering grand challenges and come to a much deeper unfolding of invention: Their list includes making solar energy economical, preventing nuclear terror, advancing health informatics, clean water and reverse engineering the human brain. None of them are just devices. Nearly all address complex social issues that require innovative technology and systems approach to solve but cannot be solved in a vacuum. They will also require engineers to shape public policy, transfer technical innovation to the market place, and to inform and be informed by social science and the humanities. These are challenges to “change the world,” and many of them are inherently global. (NAE, 2012)

I began the present work with a call for an integration of the skill of listening and of stopping or at least slowing down in the teaching of engineering. I have offered one idea or path as to how such a skill might be included in a specific course—that being an undergraduate fluid mechanics course in a bioengineering curriculum. The approach will include frequent and constant integration of meditation and other described techniques as well as a conscious effort to make connections among the subject matter and, in this case, the fluid mechanics of living systems. A research question is offered as is a theoretical foundation and methodology. If successful, understanding is increased and can be documented; I shall integrate the contemplative pedagogy in all of my teaching. Maybe I can create a bit of anti-entropy. I encourage others among us to also consider the idea.

**References**


