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Abstract
Since the 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. The outcomes of this inquiry include a set of research questions for scholars in engineering ethics and engineering studies, and a Grand Challenges lesson plan for classroom implementation that focuses students on the ethics of problem framing, and the consideration of social questions as an integral part of professional ethics.

Introduction

Since the National Academy of Engineering (NAE) first publicly articulated the Grand Challenges in 2008, engineering educators have responded explicitly by creating "grand challenge" courses[1-3] and curricula for both K-12 and undergraduate students,[4-5] and by utilizing the grand challenges to bolster arguments for working toward more integrated, multidisciplinary, development-and-sustainability focused approaches.[6-9]

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 relate in some way to sustainability or humanitarian efforts, and most require holistic thinking that transcends the narrow traditional disciplines of engineering.

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 topics have been addressed elsewhere,[10-15] the descriptions of the Challenges mostly do not include ethical analysis.

This paper, along with others in this session, 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? Ought they be undertaken at all? Such questions are a place to begin engaging the ethics of the Grand Challenges.

It may be that we 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?

I believe that there is in fact much to gain by examining the Grand Challenges in light of engineering ethics. It 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,[16] deepening the conversation by reflecting critically on the Challenges and the processes that produced them.

Gary Downey[17] among others has pointed out that problem framing is as important as it is neglected in engineering education. In this case, the NAE has defined the scope of several problems that constitute the "grand" work of the profession in this century. If we think critically about the framing of these ideas, it leads to questions in four key areas:

*Who participated in this framing, and by what process? Who was left out of the deliberations, or given a lesser role?
* 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?
* 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?
* What ethical consideration was given, or needs to now be given, to the means by which we might strive to meet such challenges?

Table 1. NAE's Grand Challenges[18]
Make solar energy economical
Provide energy from fusion
Develop carbon sequestration methods
Manage the nitrogen cycle
Provide access to clean water
Restore and improve urban infrastructure
Advance health informatics
Engineer better medicines
Reverse-engineer the brain
Prevent nuclear terror
Secure cyberspace
Enhance virtual reality
Advance personalized learning
Engineer the tools of scientific discovery

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 questions as an integral part of professional ethics.

Who decided these are the challenges?

The committee that developed the Grand Challenges (listed in Table 1) 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 were 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. All were over 35 with impressive career records, including at least 12 members of the National Academies. Data on race and ethnicity were not available.[19]

Input was sought from the general public via the NAE website. The NAE boasts that over 1000 people from over 40 countries submitted comments.[20] 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 as for the Committee members, but it is worth noting that 26 of the 49 are members of the National Academies.[21]

Why were particular individuals chosen to participate on the Committee or as reviewers? Why was the committee 100% 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.[22] Managing the Nitrogen Cycle is a passion of Rob Socolow, whose work is cited in the write-up.[23] He is also deeply involved with Carbon Sequestration, another one of the Challenges, where he is cited again.[24] This raises a question about framing – why the heavy emphasis on personalized medicine in Engineer Better Medicines? Why wasn't the Carbon Sequestration Challenge 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 Engineering 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 in 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.[25] The argument for Advancing 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.[26] 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.[27] For example, in addressing the world's need for clean water, the discussion emphasizes high-tech solutions such as nanofiltration and desalination[28] over widely available low-tech solutions such as filtration with local materials.[29]

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."[30] In this one-way trajectory, technology pushes history forward. An alternative view would be the idea of co-construction of technology and society,[31] 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.

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).[32] 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."[33] 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."[32] 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[34] 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 appropriate Grand Challenge.

Similar arguments can be made around other Grand Challenges. For example Advancing 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.[35] An apparently un-ironic reference to The Matrix[36] holds up Trinity's "downloading" into her brain a learning module on how to fly a helicopter as an ideal to be attained. 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.[37]

What does the choice of certain ends imply about the means? Langdon Winner[38] 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 the world to have access to clean water, or want to prevent nuclear terror? 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 Addressing Decaying Infrastructure in the United States 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.

The piece on Engineering 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."[39] 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 "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. Thus, Engineering 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."[28] 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."[28]

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.

Finally the Grand Challenge of Preventing 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.[41] 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 Preventing 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).[42] 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 prevent nuclear terror by eliminating the need for nuclear weapons. 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. George Catalano's call to engineers to contemplative action for peace[43] would, in my view, constitute a Grander Challenge, more difficult yet morally transformative.

Taking these questions into the classroom: Lesson Plan

Because the time one can dedicate to a lesson or unit on this topic varies widely, as does class size and teaching methods that make sense in a given context, I provide a rough sketch of how one might incorporate some of the ideas presented here in undergraduate engineering classrooms. I have not yet implemented any of these ideas, but hope to soon.

First, students could explore the NAE website. It is a fully developed and rich source of information on the Grand Challenges. Students could reflect on the following questions, and potentially write a brief essay, share results electronically, or share with a partner/small group in class:

1. 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. 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. In a more expanded unit, students could be assigned as homework to 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.
4. For students somewhat familiar with ethical thought, as an assignment outside of class, students could choose one of the Grand Challenges as defined by the NAE, and write some ethical questions that arise from the proposal. Should the Challenge be pursued? Why or why not? Consider ethical arguments both for and against pursuing the Challenge. Think about who benefits and who bears the cost. It is helpful to require students to answer these questions using a diverse set of theoretical perspectives of ethical frameworks, assuming they are facile with this.

5. Now assuming the Challenge goes forward, what are some ethical questions about *how* the challenge should be pursued? Are there ways to go about it that would be more ethical, or less ethical/unethical? Why? Who should be involved and why? In an expanded unit, an in-class small group activity might be to hold a mock community forum of different stakeholders for the given Challenge. This provides contrast to the theoretical perspectives in #4 above with contextualized perspectives grounded in the lives of individuals or communities. Each stakeholder articulates a perspective on how the Challenge could be met (or should not be met), and if there is time the group tries to work together toward consensus on what action is appropriate.

These activities focus students on the ethics of problem framing, and on the consideration of larger social 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 social justice, and students engage in the process of critically questioning a nationally authoritative body in the profession.

Conclusion

This inquiry has produced an initial set of questions for engineering ethics and engineering studies scholars to pursue further, and a Grand Challenges case study for classroom implementation that focuses students on the ethics of problem framing, and the consideration of social questions as an integral part of professional ethics.

Ultimately both pursuits question whether it is appropriate 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 would invite epistemologies and knowledges outside of engineering, including especially science and technology studies, which has much to offer engineers' understanding of the role of technology in society. 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.

The intent of this paper was to spark dialogue about the ethics of the Grand Challenges – both the specific challenges described and the process that produced them. May the conversation continue.

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