

## **Understanding the Impact of Engineering Through Engagement with the National Academy of Engineering Grand Challenges**

**Dr. Elizabeth Fife, University of Southern California**

Sr. Lecturer, Engineering Writing Program, Viterbi School of Engineering, University of Southern California. Expertise areas include: communication in collaborative environments, multidisciplinary groups, and far-flung virtual teams, communication support for open innovation inside and outside the enterprise, and finally, techniques to support global multicultural organizations. Dr. Elizabeth Fife has taught technical and professional communication courses in the Viterbi School of Engineering and the Marshall School of Business at USC for the past 17 years. Elizabeth has taught undergraduates, graduate students and engineering and industry professionals the core elements of technical writing and presenting for academic and business audiences. In addition, Elizabeth has developed specialized modules and workshops for companies in the ICT industry as well as for international companies and students in Korea, China, Japan and other Asia-Pacific countries. Education: Ph.D., International Relations, University of Southern California. Research Interests: - Collaborative environments for innovation (wikis, social networks and other collaborative online platforms), emerging economies development and the role of IT/communications technology, and methodologies for measurement and assessment frameworks

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**Elizabeth Fife**

**EWP, Viterbi School of Engineering, University of Southern California**

## **Abstract**

This study reports on pedagogical efforts supported with a structured survey to motivate engineering student's awareness of technological context. Through the University of Southern California's Viterbi School of Engineering's required writing course, (WRIT 340), several ABET criteria are addressed, including understanding the effects of engineering in a global, societal, economic, environmental, and context. To further this goal, in an intensive 3-month long process, students working in small collaborative groups master the complex issues surrounding one of the fourteen goals that the National Academy of Engineering (NAE) has identified as important technological targets for the twenty-first century.

Students are surveyed at three points during their research process (at the beginning and middle stage and then after completion of a white paper that identifies the scope of a specific problem such as environmental sustainability, health, security, and the potential and limits of new technologies to address these issues. Survey results indicate that initial positivistic views of technology are challenged through research on this project, and at completion of their research, students have gained a greater appreciation for the interplay between technology and society as implementation, public policy, resource availability and other elements affect technological choices and investment. In class discussion helps students see the linkages between what initially appears to be discrete issues as the overlap of political, economic and social factors that determine outcomes in many cases is similar.

As part of each team's final report, they consider the ethical and policy implications of the technologies they review. The Grand Challenges provides a useful "anchor" to help students approach engineering through awareness of ecosystems, sustainable development, resource management and appropriateness of technology for more holistic solutions. Such an understanding can help students become better decision-makers as they gain appreciation for the non-technical issues that affect engineering. Communication skills are also furthered through focusing on impact and consequences of technology (or the lack thereof). Students gain awareness of their role as engineers and the need for responsible dissemination of information to guide choices that affect the quality of life for all.

## **Introduction**

The National Academy of Engineering's (NAE) Grand Challenges were broadly developed in large part to help focus attention on key issues of global importance that require engineering solutions as noted by Norm Augustin, either "as part of their solution or, unfortunately, as part of

their cause.” (Augustin, N., 2007).

(<http://www.engineeringchallenges.org/14373/GrandChallengesBlog/Augustine.aspx>. Beyond the attempt to categorize and rank the issues that society in the next century will face which require engineering solutions, the Grand Challenges are intended to provide a new engineering education paradigm to give engineering students a wider understanding of context, complexities and an appreciation for the global nature of problems and solutions. Additionally, in thinking through efforts to confront the needs of humanity and sustain the planet, it becomes clear that multidisciplinary actions that bring together engineers from various disciplines along with specialists in non-technical fields is a necessary challenge unto itself.

Providing students with evidence of this need as they proceed to develop their professional ethos is perhaps another means of breaking through disciplinary barriers within engineering and between engineering and other fields. Finally, in grappling with thorny socio-economic and structural issues that both contribute to and are necessary to solve the immense tasks that will be faced in the next century, engineering students gain motivation to develop communication skills as the need to promote understanding for policy change and coordination can occur to support the use of technologies. Thus, the NAE has sought to expand the traditional benchmarks of engineering outcomes beyond considerations of cost and efficiency to measures that take into account the complexities of politics, resource scarcity, and sustainability issues, social and cultural drivers as well as unintended outcomes.

The platform of the Grand Challenges, thus offers several immediate and longer term pedagogical supports. Incorporation of the Grand Challenges into a required upper division undergraduate writing course for engineering students (WRIT 340) at the Viterbi School of Engineering, University of Southern California has provided opportunities to develop communication and research skills that are aligned with the objective to increase understanding of how engineering interacts with societal forces and how to communicate to the multiple audience that take part in the decision-making, assessment and research, and implementation of technological solutions.

The use of real world problems in the classroom to underscore societal and ethical concerns predates the NAE Grand Challenges, as many instructors in the past have used specific examples to excite students and guide them to the social, ethical and legal implications (Etter,1994). Researching and writing about important problems that are at the global level and thus have broad impact is thought to improve communication skills, understanding of interdisciplinary and multidisciplinary collaboration, and insight to the non-engineering features of a problem that must be addressed.

### **NAE Grand Challenges at the Viterbi School of Engineering**

As an advocate for the Grand Challenges, the Dean of USC’s Viterbi School of Engineering has organized two national summits and was instrumental in the establishing the Grand Challenges Scholars initiative that provides specialized programs for Grand Challenge engineers that include: 1) hands-on research that is tied to the Grand Challenges, 2) interdisciplinary experiential learning with a variety of stakeholders, 3) experience with innovation and entrepreneurship, 4) global and cross cultural perspectives and ) service-learning. Over a quarter

of engineering schools in the US have or are in the process of setting up programs (Duke University Program website, 2015).

### **Grand Challenges Scholars Experiences at Multiple Universities**

A brief questionnaire answered by Grand Challenges Scholars at a few select universities provides insight about engineering students who have an existing interest in gaining exposure to a wider breadth of social and cultural issues and how they interact with engineering and technology choices. Students on the whole joined the Grand Challenges Scholars Program to due to the breadth of topics covered, the opportunities it could offer, and of course the distinction of being selected for this program. In addition, access to funds for projects and other activities was considered a benefit.

Most students claim that they have had valued engagements, involving experiences abroad, volunteering to help new engineering students, writing papers and presenting posters. Grand Challenges Scholars also found that involvement has given them greater awareness of global issues and non-engineering factors that are important. One student remarked that it has been eye-opening to see different situations in the world outside of the US and how people are trying to cope and find solutions.

In sum, it appears that the Grand Challenges Scholars Program offers an opportunity to more fully expose engineering students to a global perspective that can shape their career choices in the field. An area where students have noted that they have not attained as much benefit as they had hoped is in learning more about engineering science and research, as well as meaningful interactions with students and faculty. Students find that they have had exposure to research, but on the whole, would like further chances for involvement. Given that undergraduate involvement in research has been identified as a “high impact” area for increasing student success (Kuh, 2008) this is an area of opportunity for further enhancement.

Grand Challenges Scholars represent a selective group of students who actively sought the opportunity to gain a broad perspective. Many of these students are already engaged in interdisciplinary pursuits and involvement in the Grand Challenges is an additional broadening experience. The undergraduate engineering population that enroll in the required technical communications course may not have this focus or exposure. The majority surveyed reported that they had limited exposure to courses in the social sciences, and virtually no experience with coursework that covered ethical principles or application of ethics to engineering.

The NAE Grand Challenges has been the basis for an NSF-funded Research Experience for Undergraduates (REU) site as well (Burkett, et.al, 2015). Overall student participants valued the chance to contribute to research on currently relevant and exciting problems of a critical nature.

### **Use of the NAE Grand Challenges in a Required Technical Communications Course (WRIT 340)**

Many students in the Viterbi School of Engineering at USC required writing class, WRIT 340 complete a final collaboratively written report (White Paper) that examines the social, economic

and political implications of one of the emerging technologies identified in the National Academy of Engineering's "Grand Challenges, [www.engineeringchallenges.org/challenges.aspx](http://www.engineeringchallenges.org/challenges.aspx). Note: some faculty use alternative assignments involving experiential learning and community-based projects.

### **Assignment Mechanics**

The well-known list of 14 technical "challenges" include solar energy, medical innovations, virtual reality, informatics and other tools, methods and approaches to improve humanity's future such as fusion, carbon sequestration, etc. are provided to students who view the NAE Grand Challenges websites which has links to resources and videos that describe technical solutions to primary global issues (e.g. resource depletion, climate change, etc.) and the rationale behind the list of the existing Grand Challenges. This well-integrated, credible and accessible source provides a well developed introduction to the student's project.

Students self-select one of the 14 challenges and form groups based on interest and skills (and often schedule convenience). Students identify an audience (government, professional organization, including the EPA, NIH, UN, etc.) that is interested in promoting research to address an issue that can be addressed by technology described in one of the Grand Challenges. The task is to review the state of the art in the relevant research areas and provide assessments and recommendations. As part of the discussion of technologies and scientific advancement that is reviewed, students also describe and analyze the social, economic and systemic issues that affect the technology's use and overall feasibility. Additionally, the ethical issues associated with the technology and the issue it is addressing need to be covered. From this analysis, recommendations for the organization are offered.

Schedules, delegation, and milestones are established in line with standard group project processes. The open-ended and broad nature of the Grand Challenges project requires initial hands-on discussion with student groups to guide them to a focused effort. Once students have narrowed the topic to a manageable level, it seems that structure and form can be determined. There is often relief expressed after this initial hurdle is overcome and a more predictable work flow for completing the project can be put in place. In addition, in class discussion becomes fruitful as students gain depth of knowledge of their topic and draw lessons from fellow students' efforts.

In sum, students explore the technology in line with the issues that these technical solutions will address in order to understand the underlying societal, economic, and political drivers. The accompanying ethical dimensions of scarcity, unequal distribution of resources and power inequity are a few of the immediate realities that are investigated. While understanding the importance of engineering solutions, students hopefully confront the complications of political, economic and social realities that challenge positivist notions of technical progress.

### **Assessing the NAE Grand Challenges in the Classroom: Student and Faculty Experience**

The ability of the WRIT 340 communications course to develop student's sense of the role of engineering's value and the consequences of technology use is evaluated through ABET surveys

carried out over the past 11 semesters, individual surveys, and student and faculty assessment. Graded assignments (the final Grand Challenges collaboratively written white paper and presentation) are the primary way that faculty measure assignment success. While different ability levels and motivation exist, this project is considered the culmination of communication and research skills that have been honed through the semester.

Student feedback suggests that some of the individual Grand Challenges generate more enthusiasm than others- this is revealed in final efforts tend to be more successful if the topic was sufficiently manageable and sparked interest. Top choices over the past three years include urban infrastructures, fusion, reverse engineering the brain, water, and education. Less frequently selected topics include development of carbon sequestration methods, managing the nitrogen cycle and engineering the tools of scientific discovery. Overall, students are satisfied with the range of topics included in the Grand Challenges, although in line with Livingston's (2012) consensus observation, the challenge regarding enhancing virtual reality does not strike students as a fundamental area, relative to the other challenges.

Perhaps the specialized nature of the former and the broadness of the latter topic contribute to difficulties in focus, and hence, sufficient coverage and interest in the topic. Students in fact who have initially selected either the carbon sequestration or managing the nitrogen cycle have universally moved towards another topic area within the subject area of climate change. To ensure the best learning and experiential outcomes, management of the topic selection and the research process requires varying levels of faculty involvement, depending on motivation and capabilities of individual student groups.

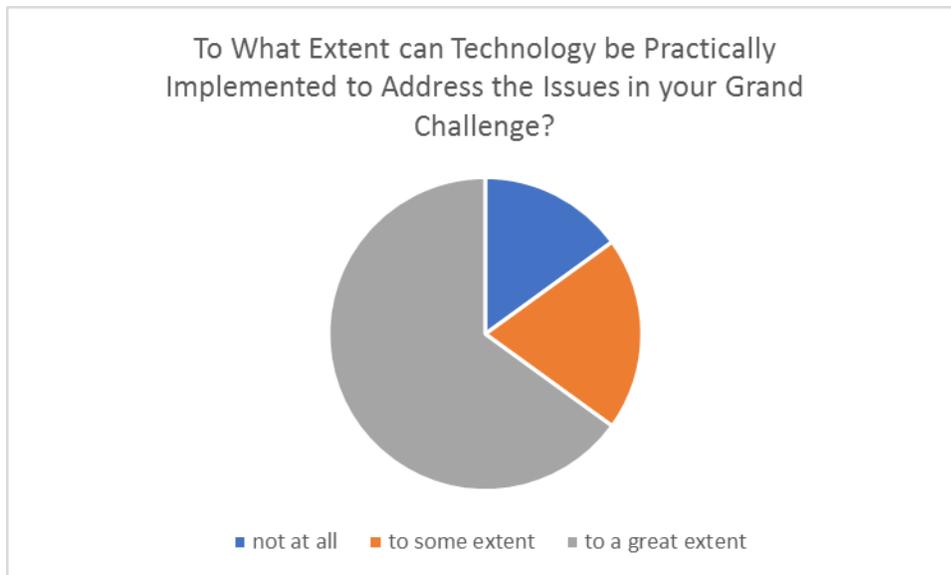
Interestingly, when the assignment is first introduced which involves reviewing the NAE Grand Challenges website, students find that the topic areas are representative of core global issues, but when asked for their analysis of the challenge choices at a later point (several weeks after the first introduction of the NAE website), they see many more challenges that they suggest for inclusion. This perhaps suggests that assignment has opened new areas of inquiry, interest and awareness. Suggestions for other topics include current problems such as famine, war, species extinction, and political dysfunction.

Feedback throughout the research and writing process is a critical underpinning of the student's experience. Faculty-familiarity with all the Grand Challenges topics has been crucial to the ability to calibrate the level and accuracy of technical description that the students present, in addition to guiding student's inquiries into their topic. An assignment earlier in the semester that involves researching and writing about the science and engineering behind an idea, product, or process provides the experience for navigating academic work and more applied treatments of their subject matter. Frequent meetings with the research teams is useful for monitoring student understanding of their topic and for directing them towards resources.

Figure 1 below reflects student's perspectives as they begin their research. At this point, students have looked at the Grand Challenges website which identifies the challenge and potential technological remedies. Students have not yet conducted independent research on their specific challenge. The majority of students at this point have a sense that development of the scientific or technological solution is the endpoint, and as evidenced in classroom discussion

have awareness regarding constraints that can limit implementation. In Fig. 1-3, the survey results from three sessions of the WRIT 340 undergraduate course between Spring 2016 and Spring 2017 (n=55) are shown. As displayed below, the majority of students believe that technology can realistically and feasibly be employed to address the issue or problem posed in their grand challenge.

Figure 1: Technology is seen as a solution to problems identified in Grand Challenge



In preparation for the research tasks of this project, students spend one class session with a research librarian who directs the class to specific databases and instructs them in search techniques and evaluation of sources. Students at times express frustration with material that is beyond the undergraduate expertise level, but exposure to basic research is part of gauging their understanding of topical scope. In addition, students on the whole have less familiarity with public sources that provide social indicators relevant to their topic. To address this and to help ensure that technical solutions are integrated with social, political and economic constraints a class session is devoted to identifying relevant source material with the assistance of a research librarian. This step has alleviated a natural tendency to concentrate on explanation of technical aspects of a particular Grand Challenge in isolation to the wider environment, feasibility issues and the range of non-technical influencing factors. Previous analysis (Williams, 2012) has noted that faculty need to provide instruction around the non-technical dimensions of the student's research efforts to avoid focus on the technical side of the solution.

Finally, a physical limitation noted by students and recognized by faculty is lack of sufficient time for student's to fully explore their topic and executing their strategy for research, writing and presenting. Also, the vast majority of the engineering students are not accustomed to writing and researching substantial and lengthy papers. Given that this assignment is carried out in addition to many other preparatory assignments in this single course that includes technical descriptions, technical oral presentations, and an ethics research paper, and another technology-oriented research paper for non-technical audiences, tackling a Grand Challenge feels daunting

to most and can truly be considered a challenge in itself! As shown below in Figure 2, gaining greater understanding of global issues and the role of technology, were knowledge areas that were perceived by the students as being improved. Along with greater understanding of global issues, students also to a great extent (40%) gained experience working on a team, 48% found that they gained expertise in terms of time management, and 50% gained better understanding of how research is conducted.

Figure 2: Grand Challenges Project Promotes Understanding of Global Issues and Complexities and Limitations of Technology Solutions

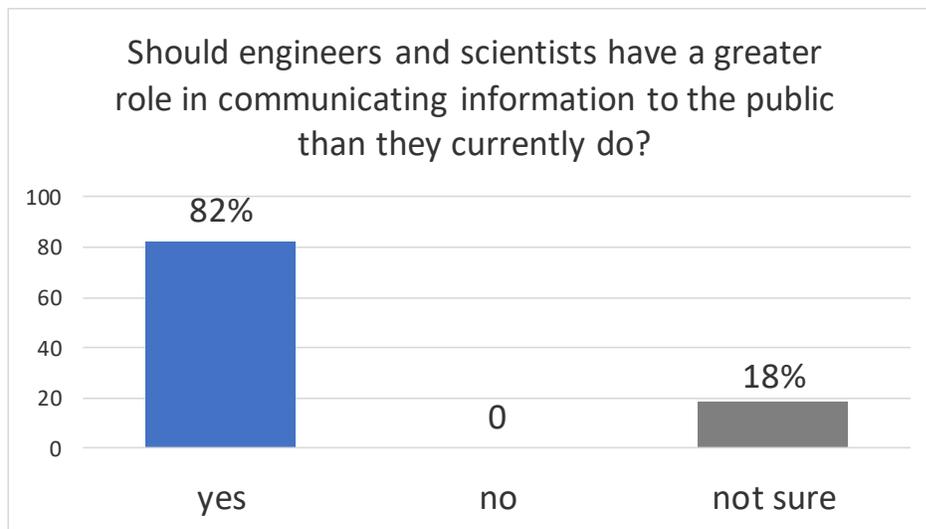


As background to student attitudes about communicating scientific information, a question posed to students in general in WRIT 340 course is whether engineers and scientists should have a greater role in communicating scientific information to the public than they currently do, seen below in Figure 3. The basis for posing this question emerges from discussions about the need for social, political and economic cooperation to occur beyond a national level in order to truly make some of the Grand Challenges a priority. Advancing research on fusion for instance or research on efforts to combat climate change including carbon sequestration seem to require a collective prioritization. Cumulative results for this question reveal that students overwhelmingly feel that engineers should take a role in communicating technical knowledge to the public to further informed decision-making.

While this result cannot be attributed to student efforts on the Grand Challenges project, it is worth noting as a value that could be further encouraged to help engineers of the future develop the necessary skills and create needed conduits to communicating more directly with the public.

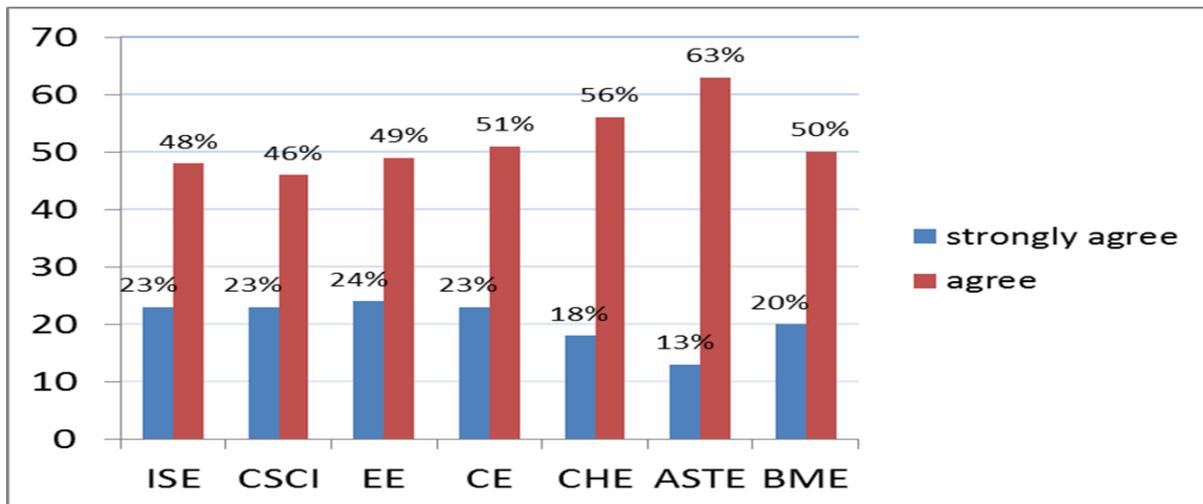
Note: this question has been posed to successive classes of 340 writing students over the past 2 years at the end of the course. Thus, the cumulative efforts put forth in the class including discussion of current global issues as well as focus on the specific topic of the role of engineers and scientists in communicating scientific information to the public has occurred at the time this question is posed. In relation to the Grand Challenges project each student group pursues, the link between technology solutions and implementation includes realization that for resources and organized efforts to be devoted to addressing a particular issue, galvanizing action necessitates communication to decision-makers, recipients, and the general public. How best to accomplish this is a bigger question that every group of students tries to reason through.

Figure 3: Overwhelming Majority Think Engineers and Scientists Should Play a Larger Role in Communicating to the Public



Overall, the success of efforts to broaden students' understanding of how engineering interacts with global issues is shown in results of program-wide survey over 10 semesters, that has been carried out for ABET purposes. This is shown in Figure 4 below which represents a sample of 2,500 students (all students enrolled in WRIT 340 were surveyed, this Figure 4 represents a larger population than the other survey results presented above). This result reflects the experience gained through the NAE Grand Challenges research paper as well as the other supportive assignments of WRIT 340 that lead up to this effort. As can be seen, the majority of engineering students report that they did improve their understanding of the role of engineering on a global level.

Figure 4: Respondents Beliefs that they Developed Understanding of Engineering’s Impact in the World



Abbreviations represent various engineering departments at USC’s Viterbi School: Industrial Systems Engineering (ISE), Computer Science (CSCI), Electrical Engineering (EE), Civil Engineering (CE), Chemical Engineering (CHE), Astronautical Engineering (ASTE), and Biomedical Engineering, (BME)

## Conclusion

Use of the NAE’s Grand Challenges as a way to cultivate deeper thinking about global issues and the role of engineers appears to be successful as a part of an engineering communications course that also includes instruction in ethical dimensions of technology, audience analysis and other components of technical writing and oral presenting. The student survey results overall suggest that interaction with the NAE Grand Challenges has helped students consider the role of engineering on a global societal basis and their personal responsibilities to communicate accurate technical information to a wider population. Assessing precise outcomes is difficult, but it seems likely that on the whole, that exploring the Grand Challenges contributes to an expanded outlook and purpose, and perhaps supports more thoughtful decision-making in student’s careers as engineers.

The open-ended nature and complexity of each Grand Challenge forces students to creatively structure their approach to complex issues that do not have definite “right” answers. This

exercise is both uncomfortable for students accustomed to quantifiable experiences, but rewarding in the discovery of pathways that can actually address serious impending problems and improve people's lives. Thus, the use of the Grand Challenges as a platform for research and writing in communications course appears to provide a meaningful way for students to connect the practice of engineering to a wider societal context. As a follow-on in measuring impact, it would be useful to track Grand Challenges Scholars after graduation to identify their career paths and any potential long-term influences from their involvement with this initiative.

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