

Beyond Technology: Preparing Engineering Innovators Who Don't See Boundaries

by

Richard K. Miller

Executive Summary. This short paper summarizes the importance of engineering innovators in the twenty-first century and the need for change in engineering education to produce them. It discusses the new model for education at Olin College in this context and explains the importance of broadening the content of engineering education beyond technical subjects. The paper ends with a call for a new national dialogue on promoting change to enhance innovation among engineering graduates.

Context. Although Olin College offers only engineering degrees, it does not simply produce engineers. Instead, *“Olin College prepares students to become exemplary **engineering innovators** who recognize needs, design solutions, and engage in creative enterprises for the good of the world.”* This is our mission. This distinction has never been more important.

As NY Times journalist Tom Friedman declared several years ago, “the world is flat”¹. The rise of geopolitical and economic fortune in the BRIC countries (Brazil, Russia, India, and China) and elsewhere appears inevitable, and over time, is likely to bring significant benefits across the globe. However, it is also likely to bring unprecedented change within America in the 21st century as we learn to cope with increased competition for economic market share, resources, and geopolitical influence. The recent financial crisis clearly illustrated the effects of global economic interdependence and the extent to which changes in the American real estate market are linked to a multitude of other dimensions of the global economy. As a result, some observers believe that the next generation may be the first in American history to lead an economic life that is less prosperous than their parents.

Friedman noted the singular importance of the role of technological innovation in the current American economy. This observation was reinforced by the National Academy of Engineering in a series of recent reports^{2,3} and by the Council on Competitiveness. In fact, technological innovation may be the most important economic export for the U.S. in this century. Much of the economic success of the U.S. in the twentieth century was the result of U.S. technological innovation⁴. This, in turn, depends heavily on our ability to maintain a global leadership role in producing engineering innovators. These are a special breed of engineers who are creative entrepreneurial thinkers that take risks in order to make the world a better place. When they succeed at creating an innovation, it changes lives so profoundly that most people cannot remember what life was like before the innovation was introduced.

Thus, engineers play a key role in America's economic future. But there are red lights on the dashboard with respect to our ability to produce these engineers, both in the quantity and quality that they are needed. Less than five percent of the B.S. degrees granted in the U.S. this year will go to students who completed an engineering curriculum. This is down significantly from twenty years ago, and the projections are that this trend will continue. Engineering is losing market share among America's youth. The long term economic consequences of this trend are worrisome.

¹ Thomas L. Friedman, [The World is Flat 3.0: A Brief History of the Twenty-first Century](#), Picador (2007).

² [Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future](#), Committee on Prospering in the Global Economy in the Twenty-first Century: An Agenda for American Science and Technology, National Academies Press (2007).

³ [The Engineer of 2020: Visions of Engineering in the New Century](#), National Academy of Engineering, National Academies Press (2004).

⁴ George Constable, Bob Somerville, Neil Armstrong, [A Century of Innovation: Twenty Engineering Achievements That Transformed Our Lives](#), Joseph Henry Press (2003).

Furthermore, the content of a traditional undergraduate engineering education is currently dominated by courses in science, engineering, and math. While these subjects are certainly important, very little of the preparation involves business or entrepreneurship—or creativity, systems thinking, teamwork, leadership or design. These additional characteristics were recently identified by the National Academy of Engineering as critical for engineering success in the twenty-first century⁵. The leaders of many universities have now endorsed this agenda and are calling for change in the nature and content of engineering education to produce more innovators and not just applied scientists⁶.

Why Is Preparing Engineers Beyond Technology So Important? There are several important reasons for shifting the emphasis of engineering studies beyond the narrow focus on the natural sciences and mathematics, which has become the norm around the world. Perhaps the most compelling is the nature of the global challenges of the twenty-first century.

In contrast to the major engineering achievements of the twentieth century—which were all about new technological devices such as the radio, automobile, airplane, internet, etc. (*see footnote 4*)—the NAE has identified 14 Grand Challenges for the twenty-first century that are significantly more complex. These challenges may be characterized as the building blocks of global security, health, sustainability, and enhancements to the joy of living. These challenges transcend academic disciplines, political boundaries, and time zones. They all involve technology at the core, but technology alone will not solve any of them. In fact, the major technological achievements of the last century have, in some cases, contributed to the grand challenges we face in this century. We must develop a new generation of engineers who can better anticipate the unintended social, political, economic, and even religious consequences of the new technologies we implement. We must aim higher this time—seeking global outcomes that involve stable systems of human behavior, not just new technological devices.

This was the conclusion of the NAE in 2004 (*see footnote 3*). As a result, they concluded that the Engineer of 2020 will need a much broader education, well beyond the current deep and narrow technical education in the applied sciences. They specifically identify creativity, teamwork, leadership, entrepreneurial thinking, and global contextual analysis in the set of new learning objectives needed now (*see footnote 5*).

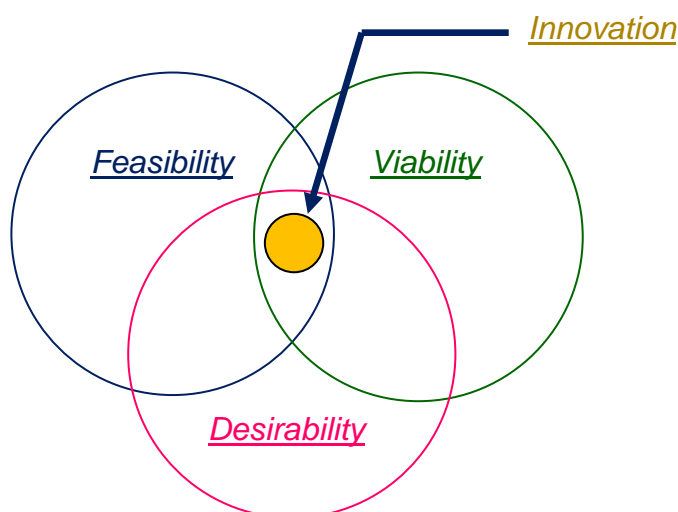
Furthermore, recent studies of the process of innovation have concluded that successful innovations always involve the intersection of three independent factors: **feasibility, viability, and desirability**⁷. Clearly, innovations require devices or systems that are feasible and therefore, obey all the laws of nature. Understanding feasibility is the primary focus of a traditional engineering education. However, to be sustainable in the marketplace, an innovation must also be viable and therefore, it must generate more revenue than it takes to create and sustain it. Understanding viability is the primary focus of a traditional business education. Finally, in order to successfully initiate an innovation in the first place, it must be desirable within a free market. Understanding desirability requires a practical competence in many things, including elements of psychology, design, marketing, and a wide range of human concerns. This is the focus of a much broader liberal education with a lens on effecting change. A graphical representation of this important concept of innovation is given in the Venn diagram of Figure 1.

⁵ [Educating the Engineer of 2020: Adapting Engineering Education to the New Century](#), Committee on Engineering Education, National Academy of Engineering (2005).

⁶ Domenico Grasso and Melody Brown Burkins, eds., [Holistic Engineering Education: Beyond Technology](#), Springer (2009).

⁷ Laura Weiss, “*Developing Tangible Strategies*,” **Design Management Journal**, Vol. 13, No. 1, pp. 33-38 (Winter 2002).

Figure 1 – Innovation Venn Diagram



I believe this model of the innovation process contains important insights for education. Clearly, for engineering innovators to succeed, they need a solid understanding of viability and desirability as well as feasibility. This requires an educational model that extends beyond technology and places an emphasis on close interaction between students with these different backgrounds and special interests. Unfortunately, this is not common in higher education today. Instead, our colleges and universities usually focus on specialization in which students sit in classes filled largely with other students from the same specialty. The result is a lack of awareness and appreciation of the role of the other two dimensions of innovation and resulting cultural differences that create barriers to communication and teamwork. To really build the insight and skills needed to accelerate innovation, it is important to place engineering students on teams with business and liberal arts students with a focus on creating innovation before these barriers have formed. It is often too late to attempt to form such multidisciplinary teams among working professionals or even graduate students within the disciplines. This philosophy is fundamental to the Olin educational model, and is enabled by our recent close partnership with Babson and Wellesley Colleges. This would be apparent by inserting the Olin, Babson, and Wellesley College logos in the appropriate circles of the Venn diagram for innovation. Our goal is to prepare engineering innovators by educating them beyond technology, so that they don't even recognize the boundaries between these disciplines. In the ideal, students won't be able to place a disciplinary label on their educational activities when working on multidisciplinary project teams.

This educational model couldn't come at a more opportune time. The current need for a serious emphasis on innovation in the U.S. is substantial. A recent benchmark study of the rate of increase in innovation in the U.S. in the last ten years placed the U.S. dead last among 40 other nations⁸. The time is right to elevate this issue and establish a comprehensive fresh approach.

There is one final reason for emphasizing this interdisciplinary approach to engineering education focused on the NAE Grand Challenges: today's students are highly motivated to make a positive difference in the world. The youth of today are naturally concerned about global climate change and

⁸ Robert D. Atkinson and Scott M. Andes, *The Atlantic Century: Benchmarking EU and U.S. Innovation and Competitiveness*, ITIF Special Report, February 25, 2009. (The ITIF uses 16 indicators to assess the global innovation-based competitiveness of 36 countries and 4 regions. The report finds that while the U.S. still leads the EU in innovation-based competitiveness, it ranks sixth overall. Moreover, the U.S. ranks last in progress toward the new knowledge-based innovation economy over the last decade. See also: "Does the U.S. Face an Innovation Crisis?" *Business Week*, September 1, 2009; "In Innovation, U.S. Said to Be Losing Competitive Edge," *The New York Times*, February 25, 2009.)

sustainable energy. They are concerned about affordable quality health care for all. They are concerned about poverty, disease, and education in developing countries. A focus on the Grand Challenges provides them with immediate relevance to the study of engineering, provided it is done in a way that engages them in meaningful self-directed projects. This has the potential to increase the attractiveness of the study of engineering among undergraduates and perhaps reverse the trend of declining market share among college graduates. Students engaged in challenging projects that are both meaningful and fun for them, are more likely to retain what they learn and persist to graduation.

Furthermore, the emphasis on multidisciplinary teams focused on relevant problems creates a highly social environment at the heart of the study of engineering. Today's youth are obsessed with Facebook and other social networking media because of a compelling need to build and sustain social relationships. The emphasis on teamwork provides an opportunity to work *with* this important new social trend, rather than ignore it, by retaining a traditional educational model which emphasizes individual student performance in technical courses that focus on problem sets and exams.

Olin College and Its Effort to Respond to the Challenge. Olin College was established for the specific purpose of creating a new paradigm for undergraduate engineering education⁹. The focus of our distinctive curriculum is to educate engineers beyond technology, to deliberately identify and recruit students into engineering that demonstrate multiple intelligences¹⁰, and to prepare them in profoundly different ways from the traditional approach. This includes learning-in-context with an emphasis on design thinking and project-based learning throughout all four years. Entrepreneurial thinking is pervasive. Every student must start and run a business in order to complete the graduation requirements. Every student also must “stand and deliver” in front of the entire community (plus about one hundred professional visitors) each semester, to enhance his/her ability to communicate persuasively and effectively. Independent learning and research are woven throughout the curriculum and in the senior year, all students must complete a substantial year-long capstone small team design project that is sponsored by industry at the \$50,000 level.

Emerging Recognition for the Olin Learning Model. There is growing recognition that the Olin learning model is significantly different from that of other institutions. Judging from the increasing number of visitors to the campus who ask for an opportunity to benchmark our work and meet our faculty and students, Olin College now appears to be on the short list of “must see” educational models for those considering major change or innovation in engineering education. A few years ago, the University of Illinois at Urbana-Champaign, requested that Olin enter into a partnership with them to help achieve a substantial change in their undergraduate program. The early results from their experiments have been encouraging, and they plan to expand the pilot program to include several hundred students in fall 2010. They have identified what they call “*the Olin Effect*” and are in the process of investigating this for future publication.

Olin College, together with Wellesley College and Babson College, recently co-hosted the Boston Summit on the Educational Imperatives of the Grand Challenges, one of a series of regional summit meetings in 2010 sponsored by the National Academy of Engineering (NAE). Nationally-known speakers at this meeting included disruptive innovation expert Clay Christensen of Harvard Business School, charter cities advocate Paul Romer of Stanford University, *Smarter Planet* advocate Sharon Nunes of IBM, and Tom Kalil from the White House Office of Science and Technology Policy. Linda Wertheimer of NPR served as moderator. The meeting was very well attended and included a number of international guests.

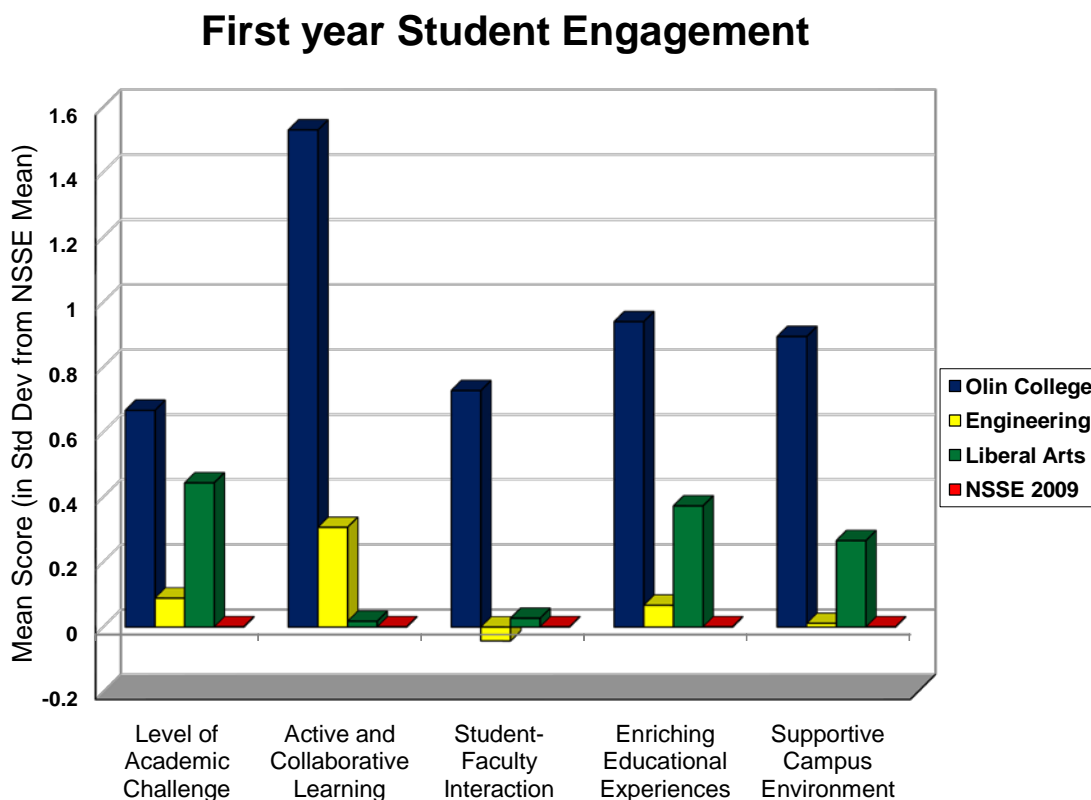
In addition, Olin College, together with partners at Duke University and the University of Southern California, initiated the National Summit on the NAE Grand Challenges at Duke University in March 2009. Olin continues to serve on the small organizing committee for a National Summit to be held next October at USC in Los Angeles. Olin College is the only undergraduate institution in such a leadership role.

⁹ Gloria Polizzotti Greis, The Founding and Early History of the Franklin W. Olin College of Engineering (2009).

¹⁰ Howard E. Gardner, Frames of Mind: The Theory of Multiple Intelligences, 10th ed., Basic Books (1993).

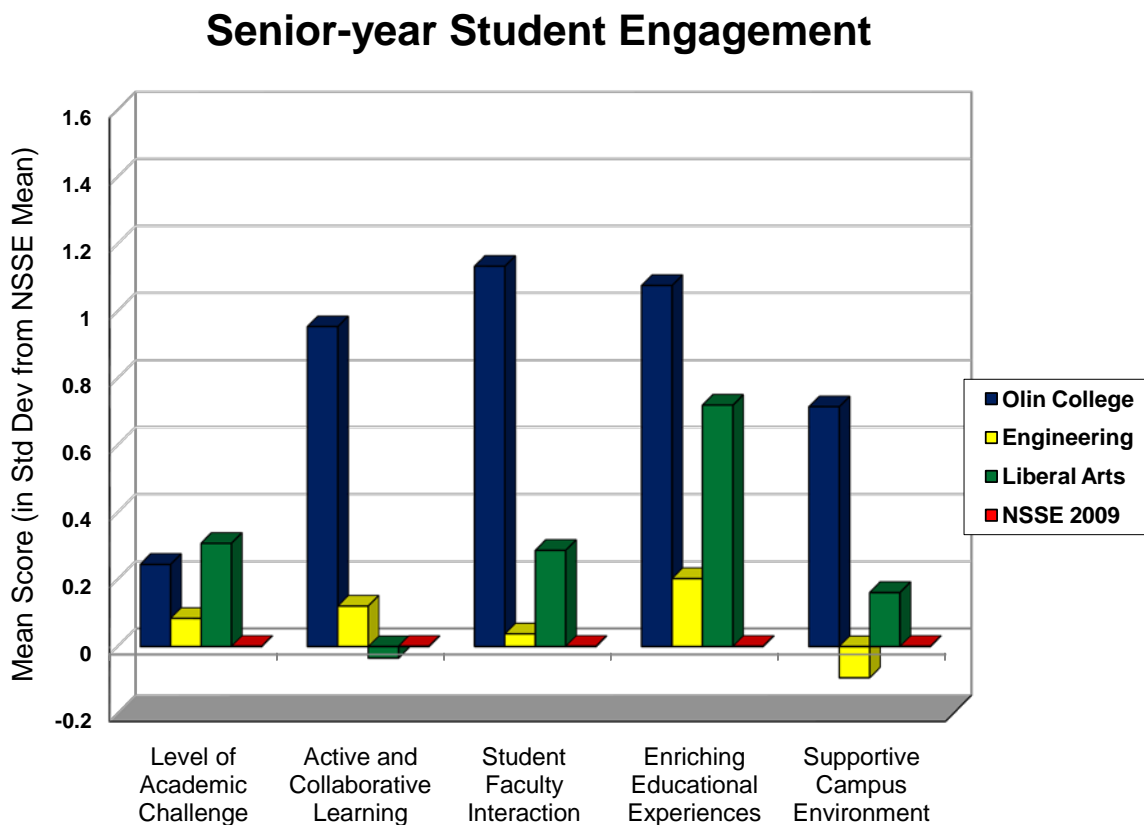
Olin Student Outcomes. The most important confirmation of the effectiveness of Olin’s learning model is based on the outcomes for our graduates. Evidence from the National Survey on Student Engagement (NSSE), administered by researchers at Indiana University’s College of Education and distributed annually by USA Today, reports convincingly that the learning environment developed at Olin College is, indeed, unusual. The survey involves several hundred colleges and universities and about a half million students across America each year. Results of the survey last year for Olin College are presented in Figures 2 and 3, for first year students and seniors, respectively. Each graph includes statistical results for five different indicators of the learning environment that are correlated with long term student learning. For each indicator, four vertical bars are shown. The blue bar represents the results for Olin’s student population. The yellow bar represents results for an ensemble of about a dozen private undergraduate engineering colleges. The green bar represents the results of a group of about a dozen selective liberal arts colleges. The red bar represents the results for the average of all colleges and universities that participated in the survey (more than 500). The results are normalized by subtracting the mean of all participants in the survey, then dividing this result by the standard deviation of all participants. (This explains why the red bar is at zero in all categories.)

Figure 2 – 2009 NSSE survey results for first year students, measured in five categories, comparing the results for Olin College with a group of undergraduate engineering schools, a group of selective liberal arts colleges, and with all participants in the survey.



While Olin's results in all indicators are excellent¹¹, the results in the area of "**active and collaborative learning**" are particularly important. More than any of the other indicators, this metric measures the amount of self-directed study and team-based project work at Olin College relative to other institutions. Learning in this mode provides the best preparation for independent, adaptive lifelong learning and teamwork skills which are critical for the 21st century. Successful engineering innovators simply must be able to learn quickly and independently in order to predict, create, and manage the technologies that will shape the future.

Figure 3 – 2009 NSSE survey results for senior students, measured in five categories, comparing the results for Olin College with a group of undergraduate engineering schools, a group of selective liberal arts colleges, and with all participants in the survey.



Sharing Olin's Learning Model with Others. According to our aspiration, Olin College "*is dedicated to the discovery and development of the most effective educational approaches and **aspires to serve as a model for others.***" We strive to share what we are learning with other larger institutions that are committed to making changes in their educational program. In this sense, Olin hopes to play the role of a "*national laboratory*" for innovation in engineering education, with the goal of starting a national movement to improve the level of creativity, design, teamwork and entrepreneurial thinking among engineers across America.

¹¹ In fact, these scores placed at or above the 90th percentile in 9 of the 10 metrics shown.

Olin College, together with Duke University and USC, established the Grand Challenge Scholars Program at the National Summit at Duke in March 2009. This program was endorsed by the National Academy of Engineering, and provides recognition for engineering students at any university who complete a voluntary enrichment program as part of their engineering BS degree including five elements: (1) a project focused on one of the NAE's Grand Challenges, (2) an entrepreneurship experience, (3) a global experience, (4) a service-learning (philanthropic) experience, and (5) an interdisciplinary experience with partners from outside the field of science and engineering. In order to be effective engineering innovators in the 21st century, engineers must be educated beyond technology and this program provides incentives and rewards for students who rise to this challenge. In an effort to spread this new model to other institutions, Olin hosted an NSF-sponsored workshop on campus last month with nearly 100 attendees, including representatives from more than 40 other engineering schools around the world¹² (see list of institutions in the appendix). This represents about ten percent of all the engineering schools in the U.S.

In response to advice received last fall from Olin's President's Council, we have established the ***Initiative for Innovation in Engineering Education*** (I2E2) at Olin College. This organized unit is designed to facilitate the process of sharing what we are learning about innovation in engineering education with other interested colleges and universities. I2E2 conducts faculty workshops in the summer, facilitates visits to Olin, promotes research and development in educational innovation, nurtures "disruptive" educational approaches, provides consultation, arranges faculty and student exchanges, internships, and other learning activities. The intent is to develop a sustainable "business model" for I2E2 that will not over extend our small faculty and staff, but enable them to continue to provide a superb undergraduate engineering education to Olin students while also participating in I2E2. This will require learning to run faculty workshops and other activities in efficient and financially sustainable ways, to help other institutions in their efforts to improve the overall effectiveness of engineering education across America and the world.

Putting This All Together, What Should We Do Next? For all the reasons outlined above, I believe it is critical that we work together to promote change in education and change in engineering to improve our rate of production of innovators. The Grand Challenges will require unprecedented levels of creativity, global cooperation, and innovation. Improvements in U.S. competitiveness will also require deliberate efforts to enhance the preparation of engineering innovators. This is unlikely to happen without change in many areas, including education. If we continue to do what we have always done, we will continue to get more of the same. Change is always inefficient, expensive, and fraught with risk. There are always reasons to avoid or delay undertaking change. It takes vision, passion, and courage to initiate change. It always takes entrepreneurial leadership and an investment.

Olin College is the result of just such an entrepreneurial investment of nearly \$500 million by the F.W. Olin Foundation to address this problem about ten years ago. We have been involved in experimentation in engineering education for ten years, and we are beginning to understand what success and failure look like in this area. Engineering schools like Olin are producing the life-blood of American industry—ingenuity and innovation. American industry is the primary beneficiary of our investment.

Olin is one of several engineering schools around the world that are engaged in serious experimentation in this area. The number is increasing each year. The 43 engineering schools that attended the NSF workshop on the NAE Grand Challenge Scholars Program at Olin last month comprise a broad set of institutions that are committed to change on their campuses. The existence of successful models is a catalyst for change and an encouragement to others. It provides vision and hope, and it takes away excuses.

¹² The National University of Singapore sent a contingent of nine faculty members (including the Dean of Engineering) who spent an entire week at Olin benchmarking our learning model and attending the Boston Summit and the NSF Workshop.

Perhaps it is time for a high level national dialogue between leaders in industry, government, and academia, about how to build on this new “movement” toward reinventing undergraduate education in engineering. It will take leadership, and Olin College is ready to help. It will take interest and commitment from high levels in industry and from other stakeholders to initiate this new conversation.

Olin is prepared to leverage its relationships with leaders in engineering education and the corporate sector, to convene a “national working group” for a twice-yearly, one-day session to define the opportunities and challenges, identify a national agenda, and create an action plan for results. We envision an emphasis on follow-up, action, and measurement. We do not envision lengthy speeches and extended studies, committees, and reports.

We might focus on defining a specific project which challenges the academic and corporate communities to work together and produce results within a year. For example, we might attempt to develop together a **metric for innovation** that would be efficient and useful for application within schools of engineering. The existence of such a metric, provided it is properly developed and tested, could have profound influence in focusing other engineering schools on producing graduates that have measurable qualities of innovation. To appreciate the potential for such a metric, consider the impact that such standardized tests as the SAT has had on the broad field of higher education for the past 50 years.

Questions. For our meeting, I ask you to come prepared to discuss the issues raised in this paper and to bring questions with you. In particular, I would like to discuss the following questions at the meeting on May 10, 2010.

1. How can business sector leaders best become engaged in a national dialogue with engineering educators to develop strategies for improving the “pipeline” of engineering innovators who are prepared to work on the Grand Challenges?
2. What role should industry play in developing and guiding the discussion on producing engineering innovators? What role should government play?
3. What role should Olin College play in this dialogue? Who else from academia should be involved?
4. Who are the leaders from industry and government that we should approach in creating the national working group?

Appendix 1

Participants in the NSF Workshop
on the NAE Grand Challenge Scholars Program

April 22, 2010

- Arizona State University
- Boston University
- Bucknell University
- California Polytechnic State University,
San Luis Obispo
- Case Western Reserve University
- Colorado State University
- Columbia University
- Drexel University
- Duke University
- Fairfield University
- Fondation RMA Watanya
- Franklin W. Olin College of Engineering
- Georgia Institute of Technology
- Kansas State University
- Lafayette College
- Louisiana Tech University
- Massachusetts Bay Community College
- Massachusetts Institute of Technology
- National Science Foundation
- National University of Singapore
- Naval Postgraduate School
- North Carolina State University
- Rochester Institute of Technology
- Saint Louis University
- Southern Illinois University, Carbondale
- The College of New Jersey
- Tufts University
- Tuskegee University
- Union College
- University of Illinois at Urbana-Champaign
- University of Arizona
- University of California, Los Angeles
- University of Iowa
- University of Massachusetts, Dartmouth
- University of Massachusetts, Lowell
- University of Michigan, Dearborn
- University of Southern California
- University of Tennessee
- University of Toronto
- Wellesley College
- Western New England College
- Wichita State University
- Worcester Polytechnic Institute