MOVING FORWARD TO IMPROVE ENGINEERING EDUCATION

Introduction

It is widely recognized that our economy, national security, and indeed our everyday lives are increasingly dependent on scientific and technical innovation. Engineering is a key component of innovation and our technological society. Changes on a global scale are rapidly occurring for engineering, and Federal leadership is needed to respond quickly and informatively. The National Science Board (Board) has issued several reports expressing concern about long-term trends that affect U.S. workforce capabilities in engineering, including the dependence on international students and workers; the declining interest on the part of U.S. citizens in engineering studies and careers; weakness in the K-12 science, technology, engineering, and mathematics (STEM) education system; and demographic trends that are unfavorable to increasing citizen participation rates in these fields.

There is a current high level of attention to engineering education from a variety of sources that have converged to make engineering education an especially timely topic for the Board to address. In addition to the Board itself, these sources include the National Academy of Engineering (NAE) reports, *The Engineer of 2020: Visions of Engineering in the New Century* (2004) and *Educating the Engineer of 2020: Adapting Engineering Education to the New Century* (2005). They also include expressed concern of U.S. industry and the public sector in engineering capabilities in the workforce; and concern over the poor progress in broadening participation in engineering.

Based on the concerns expressed from these sources, the Board decided it was timely to focus on improving engineering education, particularly with regard to the National Science Foundation (NSF)'s unique role in engineering research and education. In fall 2005 and fall 2006, the Board sponsored two workshops **with the goal of moving forward the national conversation on engineering issues by calling attention to how engineering education must change in light of changing workforce demographics and needs.** The Board feels that a continuation of the *status quo* in engineering education in the U.S. is not sufficient in light of the pressing demands for change. The workshop participants included representatives from leading engineering schools, industry, government agencies, and engineering societies. The workshops focused on key challenges for engineering education, which include the changing global context for engineering education, perceptions and often misperceptions of engineering, and difficulty in attracting and retaining students in engineering. The workshops also identified many promising programs and strategies, including both successful NSF programs and innovative programs in engineering schools and elsewhere. This report focuses on the role of NSF in building on and disseminating these innovations in engineering education.

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Key Challenges in Engineering Education

Three essential challenges for engineering education are to respond to the changing needs for engineers, to change the perception of engineering, and to retain top students.

Responding to the Changing Global Context of Engineering
Changes in the global environment require changes in engineering education. Markets, companies, and supply chains have become much more international and engineering services are often sourced to the countries that can provide the best value. Basic engineering skills (such as knowledge of the engineering fundamentals) have become commodities that can be provided by lower cost engineers in many countries, and some engineering jobs traditionally done in the U.S. are increasingly done overseas.

To respond to this changing context, U.S. engineers need new skill sets not easily replicated by low-wage overseas engineers. The problems that have driven engineering – even in recent years – are changing, as technology penetrates more of society. Systems have become more tightly coupled. Engineering thinking needs to be able to deal with complex interrelationships that include not only traditional engineering problems but also encompass human and environmental factors as major components. In addition to analytic skills, which are well provided by the current education system, companies want engineers with passion, some systems thinking, an ability to innovate, an ability to work in multicultural environments, an ability to understand the business context of engineering, interdisciplinary skills, communication skills, leadership skills, an ability to adapt to changing conditions, and an eagerness for lifelong learning. This is a different kind of engineer from the norm that is being produced now.

U.S. engineering students also need preparation for a wider set of career paths, including management and marketing. Many engineers spend a relatively short period of time – about 6 years – in engineering practice, after which they move to jobs, such as management, for which their engineering training has not prepared them well. Engineers need to be adaptive leaders, grounded in a broad understanding of the practice and concepts of engineering. Reforming engineering education along these lines is likely to improve job prospects for engineers, attract and retain highly qualified students from all U.S. demographic groups, and make them capable of addressing the complex engineering and social problems of the future.

Perceptions of Engineering
Engineering is not attracting enough people to the field, and often is not attracting the diversity of backgrounds needed. A central issue is the way that engineering is perceived by prospective students, teachers, guidance counselors, and parents.

Society at large does not have an accurate perception of the nature of engineering. Survey data indicate that the public associates engineers with economic growth and defense, but less so with improving health, the quality of life, and the environment. These perceptions persist despite the seminal contributions of engineers in the last century to providing widespread electrification and access to clean water, both with huge quality of life improvements. Such perceptions attract to engineering those individuals who are good in math and science and are interested in "things" rather than people, but not individuals who prefer to work with others on teams and who want to contribute to solving social problems. As a result, many students, especially women and minorities, cannot see themselves as engineers.

Engineers are commonly perceived as "nerds" without interpersonal skills, doing narrowly focused jobs that are prone to being outsourced. Most high school girls believe engineering

is just for boys who love math and science. Students at historically black colleges and universities may see engineering as unfriendly, unaffordable, and requiring extra preparation. They do not see a direct benefit to their community and often believe they would have to leave their community to succeed in engineering. In part due to these perceptions, engineers remain underrepresented among women, African Americans, Hispanics, and Native Americans. Engineering also is seen as unattractive by many talented and creative people who could excel in engineering but are discouraged by the rigidity of the required studies and perceptions about uncertain career prospects.

In contrast to these common public perceptions, the Board believes that it is an exciting time to be in engineering and that there are enormous opportunities for the next generation of U.S. engineers. The next generation of engineers will be challenged to find holistic solutions to population, energy, environment, food, water, terrorism, housing, health, and transportation problems. New subfields of engineering continue to emerge, including nanotechnology, biotechnology, information technology, and logistics. An infinite range of exciting new technologies and products – the future iPods and GameCubes – await development by engineers. There will continue to be a strong demand for U.S. citizen engineers in the defense and homeland security sector, as well as in the public sector. In order to align the public perception of engineering with the reality of opportunities in engineering, a conscious and sustained effort is needed to convey the opportunities and excitement of engineering.

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Retention of Engineering Students

The third challenge for engineering education is to retain those students who are initially attracted to engineering. Attrition is substantial in engineering, particularly in the first year of college. About 60 percent of students who enter engineering majors obtain a degree within 6 years. Although this retention rate is comparable to some other fields, it is especially critical for engineering to retain the pool of entering students. As noted by the Board in its 2003 report, *The Science and Engineering Workforce – Realizing America's Potential* (NSB-03-69), the sequential acquisition of skills and inflexible coursework in engineering and similar scientific disciplines means that the movement of undergraduate students from one major to another is almost entirely out during the undergraduate program, with few compensating transfers into engineering. For this reason, retention of the students is an especially critical strategy for increasing the number of students earning engineering degrees.

Engineering students often develop little identity as engineers in their first 2 years of college because they take math and science courses and have little exposure to engineering practice. Students have expressed dissatisfaction with teaching and advising in the early years, perhaps for this reason. Also, course requirements may be too restrictive to accommodate students' varied interests, and students may perceive that friends in other majors are taking easier courses and having more fun.

Some of the students who leave engineering are among the best students; others leave because they performed poorly in their first math courses. Attrition is higher than average among women and minorities – the groups most likely to lack role models in engineering. Perceptions of a too competitive and uncaring environment, fear that engineering jobs may disappear due to offshore outsourcing, and increased tuition in public universities also contribute to the high rate of attrition in engineering. Retention of engineering students is a systems problem that begins before college and involves the whole university. The Board recommended in its 2003 report on the science and engineering workforce that "the Federal Government must direct substantial new support to students and institutions in order to improve success in S&E study by American undergraduates from all demographic groups."

We commend the bipartisan efforts of Members of Congress and President Bush to provide new Federal support for scholarships and fellowships for students undertaking the study of engineering. This type of program will have a positive impact, particularly for those qualified students whose financial circumstances are limited. The pre-college preparation of entering students, the difficulty of the engineering curriculum relative to other academic tracks, the affordability of an engineering degree program, and the social experience of engineering students within the whole university all affect retention.

The workshops identified many approaches to improving retention of engineering students: introducing students to the excitement and relevance of engineering early in the educational experience; exposing students to research early on; placing engineering in a social or business context; inviting practitioners and other engineers to speak about what they do; providing role models and mentoring; providing a comfortable social environment; making extra resources available to students who need math help; making more need-based scholarships available; and working with community colleges to pave pathways for less affluent students to enter engineering.

Leading engineering schools have also had success with a variety of curricular and non-curricular programs to attract and retain engineering students. These include out-of-classroom experiences, such as undergraduate research, study-abroad programs, internships, and participation in student organizations and professional organizations; assignments to multidisciplinary and even multinational project teams; training for a diversity of career paths; hands-on engineering and integrative experiences in the first year; emphasis on social relevance, service learning, volunteer leadership, and collaboration; and systems content in addition to component-level content in courses.

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Keystone Recommendation

> ***The National Science Foundation should expand and reinvigorate its efforts to stimulate and disseminate innovation in engineering education.***

NSF has a unique and central role in engineering research and education and can play an increasing role in addressing the key challenges in engineering education. NSF supports innovation in engineering education, engineering research, and the STEM education that provides the pipeline of students for engineering. It is uniquely qualified to support innovation in engineering thinking to address the increasingly broad set of problems with which engineers must engage.

Over the last two decades, NSF has made substantial investments in a wide range of activities to improve engineering education. These include investments in: curriculum improvement, Engineering Education Coalitions, Engineering Research Centers, Model Institutions of Excellence, and Centers for Learning and Teaching. Workshop participants commended especially the contributions of NSF's (1) Research Experiences for Undergraduates (REU) program, which encourages U.S. students to pursue graduate studies by engaging them in research activities as undergraduates; and (2) Research Experiences for Teachers (RET) program, which supports involvement of K-12 teachers and community college faculty in

research activities at universities. Studies indicate that REU experiences increase interest in STEM careers and that RET experiences give teachers a better understanding of engineering and increase teacher motivation and confidence in teaching math and science. In addition, NSF addresses the issue of affordability through its graduate fellowship and traineeship programs, which include Integrative Graduate Education and Research Traineeships (IGERT), Graduate Teaching Fellows in K-12 Education (GK-12), and Graduate Research Fellowships.

Although these programs are generally viewed as being effective and helpful, they have not led to systematic changes in perceptions and retention of engineers. Moreover, best practices resulting from the programs are not readily disseminated throughout the engineering education community.

With its unique role in engineering education and research, crosscutting all educational levels and the workforce, NSF is perfectly situated to take on leadership in pursuing solutions to the issues raised at the two workshops. The Keystone Recommendation can be divided into five subsidiary recommendations. In each of these areas, there is also a need for evaluation of the programs to establish a causative relationship between funding and output.

General Implementing Recommendations

NSF should build on its innovative programs that support engineering education. In particular:

- NSF should continue and expand its REU program to college freshmen and sophomores, as well as to community college and perhaps even high school students. NSF should also look forward to facilitate the transition of REU students to graduate school through fellowships. NSF should pursue additional REU partnerships with Federal agencies, such as the National Aeronautics and Space Administration and the Departments of Energy, Transportation, and Agriculture.

- NSF should continue and expand its IGERT program to the undergraduate level. It should broaden IGERT to include research and education that integrates engineering with the arts, humanities, and social sciences to train well-rounded, dynamic engineers who can understand not only the technology but also the economic, political, and historical context for what they are learning.

- NSF should continue its ADVANCE program for Increasing the Participation and Advancement of Women in Academic Science and Engineering Careers, and consider creating a similar program focused on developing the minority professoriate.

- NSF should continue and expand its scholarship and fellowship programs, including the Graduate Research Fellowships and the GK-12 Fellows programs. In the face of rising tuitions, scholarships, and fellowships for engineering students are increasingly important, especially for less affluent students and disadvantaged minorities.

- NSF should continue and expand the RET program, and add a mechanism to keep K-12 teachers connected to the program after they return to their schools. RET can contribute in a major way to changing the perceptions K-12 students and parents have about engineering.

NSF should continue to support engineering education research and experimentation and expand dissemination of results. Successful models for attracting and retaining engineering students should be studied. Workshops could be held for sharing of practices in engineering education, such as how to mentor engineering students or how to incorporate non-technical skills (such as ethics) into technical courses. NSF should expand dissemination of best practices in engineering education through a database and Web site that provides details on successful programs and lessons learned. NSF should look into helping students make the transition to the next stage of their education; the transition from community college to engineering school deserves special attention.

NSF should support education that broadens the experiences of engineering students. NSF could provide support for programs that fund cross-disciplinary education and seminars, such as symposia that focus on the intersection of technology and the economy. NSF could support international programs by collecting data on universities with engineering programs overseas and providing support for students who otherwise would not have the resources to participate. NSF could support programs that provide global educational opportunities for undergraduate engineering students. More generally, NSF could support programs that experiment to produce different kinds of engineers.

NSF should increase its outreach efforts in order to combat public misperceptions about engineering. The NAE is supporting the development of themes to communicate a better image of engineering. NSF should work with the NAE to craft the messages it wants to convey to students, parents, counselors, and teachers. NSF should consider supporting industry-community-university partnerships that inform pre-college students and parents about engineering. NSF could sponsor workshops for guidance counselors and K-12 teachers so they understand the value of engineering, the different career options available in the field, and the opportunities in engineering for women and minorities. Minority-serving institutions could be approached for leadership in broadening participation. NSF should consider sponsoring a few highly visible "grand challenges" to attract the attention of engineers, the media, and the public, and to stimulate interest in engineering. NSF should also explore the role that industry can play in addressing instabilities in engineering employment that can lead to student concerns about career paths and therefore perceptions of engineering as a profession.

NSF should ask the National Research Council or the National Academy of Engineering to study how many and what kinds of engineers the United States must produce to be economically competitive. The Academies could examine goals for engineering education, such as a desired number of engineering graduates, percentage of graduates in engineering, demographic mix, or retention and graduation rates. It could also address the causes of the dearth of U.S.-born and -trained engineers and seek to better understand the cyclical nature of the demand for various engineering fields.

Conclusion

Worldwide, engineering is by far the largest major for first university degrees in science and engineering fields, reflecting the importance of the engineering workforce in national economic and social performance. It is therefore essential for the U.S. to attract, retain, and train American engineers from diverse backgrounds to meet domestic needs and the growing international competition in science and technology. Federal collaboration with the National Academy of Engineering, higher education, and the engineering communities is necessary to adapt engineering education to the new realities of the global workforce. In particular, NSF should reinvigorate its support for innovative engineering education to provide the leadership, knowledge, and resources to meet these challenges.

The Board's policy guidance for NSF must be implemented to ensure the adequacy and quality of the U.S. engineering workforce for the future. The Board is pleased to be able to join with our colleagues in the engineering communities to address the challenges and opportunities for engineering in the new century.

Selected Bibliography

Center for the Advancement of Scholarship on Engineering Education (CASEE), *Progress and Accomplishments: Engineering Education Research and Development* (Washington, DC: National Academy of Engineering, 2005-2006).

Farrell, Diana et al., *The Emerging Global Labor Market*, Executive Summaries (McKinsey Global Institute, McKinsey and Company, June 2005).

Hoffer, Thomas and Vincent Welch, Jr., SRS Infobrief: "Time to Degree of U.S. Research Recipients," NSF 06-312 (Arlington, VA: National Science Foundation, Directorate for Social, Behavioral, and Economic Sciences, March 2006).

Lattuca, Lisa, Patrick Terenzini, and J. Fredericks Volkwein, Center for the Study of Higher Education, The Pennsylvania State University, *Engineering Change: A Study of the Impact of EC2000*, Executive Summary (Baltimore, MD: ABET, Inc., 2006).

Ed. Mary Mattis and John Sislin, *Enhancing the Community College Pathway to Engineering Careers* (Washington, DC: National Academy of Engineering and National Research Council, 2005).

National Academy of Engineering, *The Bridge: Linking Engineering and Society*, Vol. 36, No. 2 (Washington, DC: National Academy of Engineering, Summer 2006).

National Academy of Engineering, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century* (Washington, DC: The National Academies Press, 2005).

National Academy of Engineering, *Engineering Research and America's Future: Meeting the Challenges of a Global Economy*, Executive Summary (Washington, DC: National Academy of Engineering, 2005).

National Academy of Engineering, *Enhancing the Community College Pathway to Engineering Careers* (Overview and Report Summary and Statistical Appendix) (Washington, DC: National Academy of Engineering, 2005).

The National Academy of Sciences, National Academy of Engineering, and Institute of Medicine of the National Academies, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, Executive Summary from Prepublication Copy (Washington, DC: The National Academies Press, 2005).

National Science Board, *2020 Vision for the National Science Foundation* (NSB-05-142) (Arlington, VA: National Science Foundation, 2005).

National Science Foundation, *Investing in America's Future: National Science Foundation Strategic Plan FY 2006-2011* (Arlington, VA: National Science Foundation, 2006).

National Science Foundation, *Science and Engineering Indicators 2004* (NSB-04-07), Appendix Tables 2-22 and 2-26 (Arlington, VA: National Science Foundation, 2004).

Oliver, Julia, SRS Infobrief: "First-Time S&E Graduate Enrollment of Foreign Students Drops for the Third Straight Year," NSF 06-321 (Arlington, VA: National Science Foundation, Directorate for Social, Behavioral, and Economic Sciences, July 2006).

Parker, Linda, Engineering Workforce Project, "The Education and Employment of Engineering Graduates" (Arlington, VA: National Science Foundation, Division of Engineering Education and Centers, March 2004).

Parker, Linda, Engineering Workforce Project, "Engineers in the United States: An Overview of the Profession" (Arlington, VA: National Science Foundation, Division of Engineering Education and Centers, June 2004).

Tenner, Ed, "Engineers and Political Power" (TechnologyReview.com, April 2005).

Tsapogas, John, SRS Infobrief: "More Than One-Fifth of All Individuals Employed in Science and Engineering Occupations Have Less Than a Bachelor's Degree Education," NSF 04-333 (Arlington, VA: National Science Foundation, Directorate for Social, Behavioral, and Economic Sciences, August 2004).

Tsapogas, John, SRS Infobrief: "Recent Engineering and Computer Science Graduates Continue To Earn the Highest Salaries," NSF 06-303 (Arlington, VA: National Science Foundation, Directorate for Social, Behavioral, and Economic Sciences, December 2005).