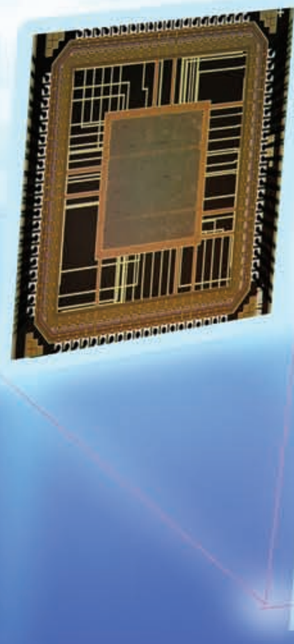
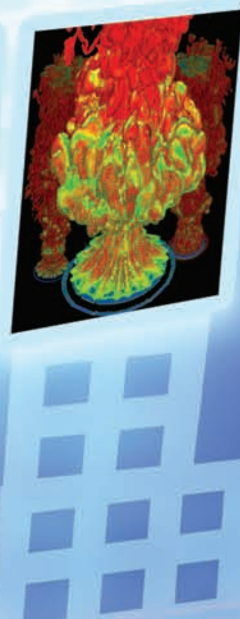
National Science Board

MOVING FORWARD TO IMPROVE ENGINEERING EDUCATION





November 19, 2007

National Science Foundation

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MOVING FORWARD TO IMPROVE ENGINEERING EDUCATION

NATIONAL SCIENCE FOUNDATION

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MEMORANDUM FROM THE CHAIRMAN OF THE NATIONAL SCIENCE BOARD

SUBJECT: *Moving Forward to Improve Engineering Education*

This report of the National Science Board (Board) lays out our findings and recommendations for the National Science Foundation (NSF) to support innovations in engineering education programs. The Board, established by Congress in 1950, provides oversight for, and establishes the policies of, NSF. It also serves as an independent body of advisors to the President and Congress on national policy issues related to science and engineering research and education.

In March 2005, the Board undertook an examination of recent recommendations addressing changes in engineering education and implications for the engineering workforce. This effort built upon the work of the National Academy of Engineering (NAE) in its report, *The Engineer of 2020: Visions of Engineering in the New Century*, as well as recent Board policy reports that identified issues of concern for the domestic engineering workforce.

Moving Forward to Improve Engineering Education synthesizes the results of two Board-sponsored workshops and significant Board deliberations. The first workshop was held at the Massachusetts Institute of Technology in October 2005 and included a range of experts representing broad interests in engineering education. For the second workshop, held at the Georgia Institute of Technology in November 2006, 23 leading deans of engineering (or equivalent) and the NSF Assistant Director for Engineering participated in discussions that identified needs for change in engineering education and model programs to address those needs.

Throughout the process, the Board maintained a dialogue with NAE and coordinated with the NAE "Engineer of 2020" project. Our recommendations in this final report address issues of public perception of engineering, retention of students in engineering majors, responsiveness of engineering education to change in the global environment, and needs for additional data to support policy and planning.

We hope that you will join the Board in supporting the critical national need for innovations in engineering education in order to both sustain a globally competitive engineering workforce and enhance career opportunities for our future engineers.

Steven C. Beering
Chairman
National Science Board

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Acknowledgments

Those who contributed to this study are too numerous to mention individually. Invited participants in the two workshops that provided the bulk of the input to our findings and recommendations are included in Appendices I and II.

We are deeply grateful for the excellent cooperation of and dialogue with Dr. William Wulf, the immediate past President of the National Academy of Engineering (NAE), and Dr. Charles Vest, the current NAE President, throughout this project, as well as the special assistance provided by Mr. Richard Taber, Program Officer, NAE.

Others who played less visible but still vital roles include Ms. Frances Marrone, Senior Administrative Assistant to Dr. Daniel Hastings, who coordinated the arrangements for the first workshop at the Massachusetts Institute of Technology, and Dr. Sue Ann Allen, Executive Assistant to the President, and Dr. Don Giddens, Dean of the College of Engineering, who coordinated the arrangements for the second workshop at the Georgia Institute of Technology.

We are especially appreciative of the cooperation and efforts of the National Science Foundation (NSF) Assistant Directors for Engineering throughout this project, including Dr. John Brighton and his successor, Dr. Richard Buckius, who is the current Assistant Director. We also appreciate the special assistance provided by other NSF staff involved in engineering education, including Dr. Russell Pimmel, Program Director, Division of Undergraduate Education, Directorate for Education and Human Resources, and Ms. Susan Kemnitzer, Deputy Director, Division of Engineering Education and Centers, Directorate for Engineering, both of whom briefed Board Members on the history of NSF engineering education programs and prepared presentation materials for the second workshop.

The National Science Board Office provided excellent and essential support throughout this project. Especially deserving of recognition are: Ms. Clara Englert, Science Assistant, who provided the primary staff support for this effort; Ms. Ann Ferrante, Writer-Editor, for editorial and publishing support; and Ms. Jennifer Richards, Science Assistant, for preparation of the final report and distribution. Dr. Michael Crosby, the Board's Executive Officer and Board Office Director, provided guidance and support to all aspects of the Board's effort.

Process for Producing the Report

This study was initiated and led by several Members of the National Science Board's (Board's) Education and Human Resources (EHR) Committee – Drs. G. Wayne Clough, Daniel Hastings, and Louis Lanzerotti. The Charge from the Board to the EHR Committee, *Workshop on Engineering Workforce Issues and Engineering Education: What are the Linkages?* (NSB-05-41), was approved at the Board meeting on March 30, 2005.

The purpose of the initial workshop was to "focus on recent recommendations for changes in engineering education and implications for the engineering workforce . . . to move the national conversation on these issues forward in a productive way by calling attention to how engineering education must change in light of the changing workforce demographics and needs." The Charge further noted the opportunity to work in parallel with the National Academy of Engineering (NAE) "Engineer of 2020" project, which called for reform in engineering education. The Board's study included the following range of inputs.

- The Selected Bibliography includes published background materials for the study.
- Two well-attended public workshops were held at major academic institutions offering engineering degrees:
    - Massachusetts Institute of Technology, October 20, 2005: *Engineering Workforce Issues and Engineering Education: What are the Linkages?* The workshop focused on broad issues in engineering education, with faculty, students, and representatives from employers and engineering professional societies. (See: Appendices I and III)
    - Georgia Institute of Technology, November 7, 2006: *Moving Forward to Improve Engineering Education*. The workshop focused on the National Science Foundation's (NSF's) role in encouraging change in engineering education; 23 leading deans of engineering (or equivalent representative of their institution) and the NSF Assistant Director for Engineering participated in the discussion with Board Members. (See: Appendices II and IV)
- Board Members coordinated with the President of the NAE to consider how the Board's effort would complement that of the NAE "Engineer of 2020" project. They held informal discussions over the course of the study and a formal meeting on August 8, 2006.
- Board Members met with NSF senior staff of the Directorate for Engineering and other staff involved in engineering education on August 8, 2006 for a presentation on and discussion about NSF's history of involvement in engineering education, and a review of the success of its programs. The Board consulted with NSF senior management for the NSF Directorate for Engineering throughout the project.

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 <u>must</u> 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.

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.

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.

…it is an exciting time to be in engineering…The next generation of engineers will be challenged to find holistic solutions to population, energy, environment, food, water, terrorism, housing, health, and transportation problems.

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.

Engineering schools may be able to learn from business and medical schools, both of which have succeeded in transforming their student bodies from predominantly male to a 50:50 male/female ratio, and have succeeded in attracting and retaining more minority students.

Engineering schools may be able to learn from business and medical schools, both of which have succeeded in transforming their student bodies from predominantly male to a 50:50 male/female ratio, and have succeeded in attracting and retaining more minority students.

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.

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APPENDICES

NSB/EHR-06-08

A National Science Board-Sponsored Workshop

Engineering Workforce Issues and Engineering Education: What are the Linkages?

October 20, 2005
The Massachusetts Institute of Technology

Summary Notes

The following summary notes of the discussions and presentations reflect the views and opinions of the participants and not necessarily the positions of the National Science Board.

A National Science Board-Sponsored Workshop

Engineering Workforce Issues and Engineering Education: What are the Linkages?

Introduction

This report summarizes the key themes and suggestions resulting from the National Science Board-Sponsored Workshop on Engineering Workforce Issues and Engineering Education, held October 20, 2005 at the Massachusetts Institute of Technology. The workshop focused on recommendations for changes in engineering education and implications for the engineering workforce presented in the recent National Academy of Engineering reports, *The Engineer of 2020: Visions of Engineering in the New Century*, and *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, and NSB[1] reports that identified troublesome trends in the number of domestic engineering students, with potential impacts to U.S. preeminence in S&E based innovation and discovery.

The major workshop objective was to move the national conversation on these issues forward in a productive way by calling attention to how engineering education must change in light of the changing workforce demographics and needs. A key output was suggestions for how NSF could help enable the appropriate changes in education through data collection and research. The workshop involved leading engineering educators as well as representatives of industry, government agencies, and engineering societies. It included panels on "Aspirations for Engineering Education," "Engineering Education - Present and Future," and "Engineering Employment – Present and Future." The workshop addressed such topics as alternative scenarios for engineering workforce and engineering education; the roles of the different stakeholders (professional societies, universities, working engineers, and employers); broadening participation in engineering; the role of foreign students and engineers; the need for engineering education to prepare students more broadly for employment in the public, nonprofit, academic, and industry sectors; and how to attract the best and the brightest students to engineering studies and careers.

Central themes of the workshop were that the current standard engineering education appears neither to provide the full set of skills that engineers are likely to need in the future nor to attract the right numbers or types of people to engineering. Workforce opportunities for engineers and skill needs vary greatly among employers. Likewise, no one approach is most effective for achieving a broader base of participation by the "best and brightest" students, and a variety of successful models should be employed. Engineering education reforms can help attract and retain highly qualified students from all U.S. demographic groups, and prepare them to be adaptive leaders, capable of addressing complex problems for the engineering jobs of the future. Speakers in the workshop felt that the present is the time for leadership in U.S. engineering education since one of the economic battlefields of the future will be over the global redistribution of engineering talent.

[1] *The Science and Engineering Workforce – Realizing America's Potential (NSB-03-69), An Emerging and Critical Problem of the Science and Engineering Labor Force (NSB-04-07).*

Key Themes

There are exciting opportunities in engineering. There continue to be exciting new subfields of engineering, including nanotechnology, biotechnology, information technology, and logistics. The next generation of engineers will be challenged to find solutions to population, energy, environment, food, water, terrorism, housing, health, and transportation problems. These problems require multidisciplinary knowledge, systems thinking, and an understanding of social issues.

The context of engineering education is changing. Markets have become more international. Other countries have a competitive advantage in low cost manufacturing and services. In some countries, excellent engineers are available at one-fifth of the cost of a U.S.-educated engineer. Supply chains are increasingly integrated across companies and nations, requiring a different set of communication and cultural skills. Other countries, especially India and China, have greatly increased their production of engineers. Conventional engineering work from conceptual design through manufacturing is increasingly outsourced to lower cost countries. The speed of change means that any set of technical skills may quickly become obsolete. To prosper, U.S. engineers need to provide high value and excel at high-level design, systems integration, innovation, and leadership.

There is uncertainty about the number of U.S. engineers required in the future. This is in part due to uncertainty about the effects of outsourcing and the role of foreign-born engineers in the United States. The United States has historically used foreign-born engineers to meet needs, but there is concern that the U.S. will not be able to attract these as well in the future. Other countries, particularly in Europe, are beginning to compete for the world pool of science and engineering talent, and more students from India, China, and other countries may choose to return home because of the expanding economic opportunities in their home countries. There was widespread agreement among workshop participants, however, that:

- Career opportunities are likely to be much greater for engineers who have a broader set of skills (described below) than for more narrowly trained engineers, whose skill set can be easily replicated by low-wage overseas engineers.
- The United States must continue to attract the "best and brightest" (broadly defined) to engineering.
- There will continue to be a demand for U.S. citizen engineers in the defense and homeland security sector, and in the public sector.
- Regardless of the number of U.S. engineers needed, the United States needs a more technologically literate workforce.
- Many in industry want to partner with the K-12 schools and universities to attract more of the nation's talent into contributing to engineering.

Engineering is not succeeding in attracting and keeping many of the right students. Students appear to be making rational, well-informed decisions when they choose not to pursue engineering. Engineering is unattractive to many people who could excel in engineering, due to the rigidity of the required studies and perceptions about uncertain career prospects. Talented students feel they can make more money and have greater job security through other careers. Many engineers spend a relatively short period of time (i.e., 6 years) in engineering practice, after which they move to jobs, such as management, for which their engineering training has not prepared them well. Negative images of engineering also make it less attractive. Dissatisfaction with teaching and advising in undergraduate engineering colleges also leads many students to transfer from engineering to another undergraduate major. Poor retention rates for students who study engineering can often be attributed to issues with teaching and advising in the first and second years, a time when the students are taking service courses, some in large sections, and when there may be little contact with engineering. Attention is needed to improving teaching, advising, and support for the students during this time. Many students who are not retained in engineering are the students who are more comfortable working in cross-disciplinary environments. It is important to attract and retain students who are creative and have leadership and communication skills, not just math and science skills.

Engineers remain very underrepresented among women, African Americans, Hispanics, and Native Americans who together constitute the majority of the U.S. population. Groups that are under-represented in engineering are growing as a percentage of the U.S. population. Focus groups with women and underrepresented minorities have shown that they want more collaborative approaches to school and work, and want a greater focus on engineering to address socially important problems. Linear progress in attracting women and minority students into engineering is no longer sufficient.

Engineers of the future need a new set of skills. If engineering in the U.S. is to help the U.S. succeed in this century, it will need to attract students who not only have basic math and science skills, but also those who exhibit common sense, an interest in commerce and innovation, an understanding of culture, a willingness to interact with people, and a desire to help humanity and life on the planet. Through their native abilities and the shaping of an education that is updated to reflect new circumstances, an engineer will emerge who can be differentiated from those educated abroad. In addition to analytic skills, which are well provided by the current education system, companies want engineers with passion; life long learning skills; 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; and an ability to change. The public sector especially needs engineers with a sophisticated understanding of the social environment within which their activity takes place, a systems understanding, and an ability to communicate with stakeholders.

Engineers should be educated with a wider set of career paths, including management and marketing, in mind. Engineers should be adaptive leaders, grounded in a broad understanding of the practice and concepts of engineering. Reforming engineering along these lines is likely to improve job prospects for engineers and the attractiveness of engineering as a profession.

There are many innovations in engineering education taking place. A wide variety of experiences with innovative approaches to engineering education were presented, including those of several NSF programs (Engineering Education Coalitions, Research Experiences for Undergraduates programs, Research Experience for Teachers programs, and the Engineering Research Centers) and several universities and colleges (Olin School of Engineering, MIT, Drexel, Georgia Tech, Smith College, University of California, Purdue, and others). Suggested approaches discussed include:

- Redefining the core engineering curriculum to free up time for other learning.
- Using content modules instead of courses to allow greater customization of curriculum.
- Focusing on threads of knowledge that connect different pieces of the engineering curriculum.
- Using student involvement in the design of the curriculum.
- Providing more diversity in types of engineering training, appropriate for different career goals.
- Using out-of-the-classroom experiences, such as undergraduate research, study-abroad programs, internships, and participation in student organizations and professional organizations, to broaden the experiences of engineers.
- Providing first year students with hands-on engineering and integrative experiences that involve design, imagination, and communication.
- Emphasizing social relevance, collaboration, and problem solving in the curriculum.
- Focusing on courses with some systems content in addition to component level content.
- Providing sophomore engineering students with internships to expose them to the practical world of engineering, including creating and marketing products.
- Putting students on multidisciplinary and even multinational project teams.
- Using more independent inquiry and open source learning.
- Providing master's degree programs in engineering management, manufacturing leadership, and system design and management.

There are some significant barriers to changing engineering education. Cost is one barrier -many of the proposed changes to engineering education involve investments in new curricula and more faculty-student interaction. Not all of the proposed changes need to be expensive, indeed several are not, but it was agreed that proposed changes need to have a business plan. Several of the engineering deans suggested that it was important that the changes to engineering education be scalable to larger numbers of students. Another barrier is that the engineering curriculum is already very tight, and adding more courses requires taking out other courses or increasing the length of the degree. Taking material out of the curriculum leads to concern that the traditional curriculum is being watered down, and there are concerns about how employers would react. Many of the proposed changes may require more faculty time in teaching, potentially detracting from research. Engineering education reforms need to come from the bottom up, but also need strong leadership and support from the top down. It was also pointed out by some of the industry representatives that education does not stop at graduation and collectively industry and academia need to think about lifelong learning.

Suggestions for Actions

The workshop generated a wide number of suggestions for future actions. These are suggestions for topics to be examined in more depth, not necessarily a consensus of the workshop participants. The suggestions pertain to pre-college education, university/college education, the engineering workforce, the image of engineering, and data/research needs.

Pre-College Education

There were suggestions to provide greater exposure to engineering in K-12 education. There should be a K-12 engineering curriculum standard to complement, enhance, and enrich the curriculum in math and science. Exposure to engineering could help to stimulate interest in K-12 math and science. It is especially important to begin engaging the interest of minorities and women as early as grades 4-6, and to continue to work with these students all the way through school. Parents and the general public also need to be engaged more through a variety of outreach and activities. It was suggested that industry and academia should interact more with K-12 schools to project a positive image of engineering into the schools. There are NSF programs in this arena, and it may be possible to strengthen them.

University/College Education

A wide variety of suggestions were focused on university/college engineering education.

Engineering schools should:

- Engage students in engineering in their first year and help students to establish an early identity as an engineer through exposure to engineering coursework, early research experiences, experiential learning, and the context of engineering.
- Address poor teaching (some in non-engineering courses) and advising that is cited by many of the students leaving engineering.
- Provide opportunities to work for the public good, to take advantage of student interest in public service.
- Develop more active learning approaches to engineering and science, as well as practical exposure to broadening engineering education, through university-government-industry partnerships.
- Rethink the curriculum to include not just knowledge, but also skills and attitudes. There should be a focus on building an understanding of what it means to be a lifelong learner and building the related skills.
- Consider offering engineering courses to non-engineers.
- Reintroduce the history of engineering into the engineering curriculum. They should teach, for example, not only the Laplace transform but also teach who Laplace was and how he influenced math, engineering, and philosophy.

NSF should:

- Use teaching evaluation scores as part of the evaluation of research proposals.
- Increase the incentives for interdisciplinary work among engineering faculty.

Universities should:

- Create and support professional graduate programs in engineering and science leadership as an analog to professional programs in business, law, and medicine.
- Create skunk works (organizations free of institutional barriers) for reinventing engineering.
- Consider developing support systems for engineering students to help them learn to manage their time and meet social needs. Providing group housing for incoming engineering students is an option.

Community colleges should:

- Be included in the discussions of engineering education. Community colleges are an important pathway to the associate degree in engineering and then to four-year degrees; their role needs to be looked at more closely.

Universities and industry should consider:

- More joint programs between universities and industry, such as research consortia and grants for personnel exchanges between industry and universities.

Engineering Workforce

Several suggestions addressed policy changes to expand the pool of engineering talent:

- Congress should create a national innovation act, with 5,000 government-sponsored portable fellowships for U.S. students in math, science, and engineering.
- Congress should expand engineering traineeships for U.S. citizens.
- Congress should change laws to provide green cards to foreign citizens who graduate in the U.S. with a Ph.D. (or master's) degree. The U.S. must retain the best and brightest of the foreign nationals who study in this country.
- NSF/NSB should expand industrial participation in this discussion of engineering education.
- With respect to lifelong learning, universities should provide courses covering recent advances in science in order to refresh engineers' education.

Public Image of Engineering

There were several suggestions to improve the public image of engineering:

- NSF could support more ways to celebrate math, science, and engineering that young people find exciting and inspiring.
- The television and movie industry, perhaps with NSF/foundations' support, could develop popular television shows or movies highlighting the role of engineers -- "Detroit Manufacturing" or "Route 128 Engineering" in a similar vein as "L.A. Law" and "Boston Legal."
- NSF could sponsor a few highly visible "grand challenges" to attract the attention of engineers, the media, and the public. For example, DARPA is sponsoring a grand challenge about robotic vehicles, and a private foundation is sponsoring the X-Prize for a private team building an efficient craft for space tourism.
- The engineering community should find a Carl Sagan-quality spokesman for engineering.

Research and Data Collection

There were several suggestions to expand research and data collection related to engineering education:

- NSF and others should fund research on problem-based learning approaches to determine if they are effective.
- The U.S. government should develop better information about outsourcing, engineering labor markets, and engineering careers, including market signals such as job openings.
- NSF should fund research and data collection on the impact of engineering research.
- NSF should study models that have worked for attracting and retaining engineering students.

Future Workshops

Several suggestions were also made for possible future workshops. It was suggested that there should be greater participation from industry, including representation from more diverse industry sectors. It was also suggested that community colleges should be included, because of the important role they play both as a stepping-stone to college degrees and in lifelong learning. In addition, it would be good to expand the dialogue to include engineering deans and faculty other than those who have been at the forefront of innovation in engineering education.

National Science Board Workshop

Engineering Workforce Issues and Engineering Education: What are the Linkages?

Massachusetts Institute of Technology (MIT)

Wednesday, October 19, 2005

7:00 p.m. **Reception and Registration**
Boston Marriott Cambridge
Two Cambridge Center
Kendall Square (Broadway and Third Street)

Thursday, October 20, 2005

NSB Workshop
MIT Faculty Club
Alfred P. Sloan Building
E52-6th Floor – Dining 5 and 6

8:00 a.m. **Continental Breakfast**
Dining 5

8:25 a.m. **Welcome**

Warren M. Washington*, Chairman, National Science Board

8:30 a.m. **Panel 1: Aspirations for Engineering Education**

Opening Remarks .... Daniel Hastings*
National Science Board

National Academy of Engineering .... G. Wayne Clough*
The Engineer of 2020, Phases I & II .... National Science Board

Data, trends, and outlooks ....Richard Buckius
National Science Foundation

NSF activities in engineering .... Arden L. Bement*
National Science Foundation

9:10 a.m. Group Discussion among Workshop Participants

9:20 a.m. Questions and Comments from the Audience

9:30 a.m. **Panel 2: Engineering Education – Present and Future**

Moderator: Daniel Hastings, National Science Board

Alice Agogino*
University of California, Berkeley

Eli Fromm*
Drexel University

Richard Miller*
Olin College of Engineering

Tom Magnanti*
MIT

Linda Katehi*
Purdue University

10:30 a.m. Group Discussion among Workshop Participants

11:15 a.m. Questions and Comments from the Audience

11:30 a.m. **Break**

11:45 a.m. **Lunch with MIT Engineering Council and Selected Engineering Students**
By Invitation Only

Susan Hockfield*, President, MIT

John H. Marburger, III*, Science Advisor to the President
Director, Office of Science and Technology Policy (OSTP)

12:45 p.m. **Break**

1:00 p.m. **Panel 3: Engineering Employment – Present and Future**

Moderator: Louis L. Lanzerotti*, National Science Board

Peter Pao*
Raytheon Company

Jim Miller*
Cisco Systems, Inc.

Ron Hira*
IEEE-USA

Gloria Jeff*
Michigan Department of Transportation

2:00 p.m. Group Discussion among Workshop Participants

2:45 p.m. Questions and Comments from the Audience

3:00 p.m. **Breakout Sessions to Address the Question: How do we ensure that the best and the brightest students pursue engineering studies and careers, and that their education quality, content, and teaching are of the highest caliber?**

Location: Dining 3, Dining 5, and Dining 6

Session Chairs: G. Wayne Clough, Louis L. Lanzerotti, Daniel Hastings

4:30 p.m. **Report Out and Wrap-Up**

Moderator: Daniel Hastings*

5:00 p.m. **Reception**
MIT Engineering Systems Division (ESD)
Building E40-298

* Confirmed speaker/moderator

National Science Board-Sponsored Workshop

Engineering Workforce Issues and Engineering Education: What Are the Linkages?

Massachusetts Institute of Technology
Cambridge, Massachusetts
October 20, 2005

Invited Workshop Participants

Participant	Affiliation
	National Science Board
Dr. Warren Washington*	NSB Chairman
Dr. Dan Arvizu	NSB Member
Dr. G. Wayne Clough*	NSB Member
Dr. Daniel Hastings*	NSB Member
Dr. Elizabeth Hoffman	NSB Member
Dr. Louis Lanzerotti*	NSB Member
Dr. Jon Strauss	NSB Member
Dr. Michael Crosby	NSB Executive Officer
	National Science Foundation
Dr. Arden Bement*	NSF Director
Dr. Richard Buckius	NSF Interim Assistant Director for Engineering
Dr. Donald Thompson	NSF Interim Assistant Director for Education and Human Resources
	Participants
Dr. Alice Agogino*	UC-Berkeley, Professor of Mechanical Engineering
Dr. Sue Ann Bidstrup Allen	Georgia Tech, Executive Assistant to the President
Mr. Richard Anderson	ABET, President
Dr. Robert Armstrong	MIT, Head of the Department of Chemical Engineering
Dr. Joseph Bordogna	University of Pennsylvania, Professor of Engineering (formerly NSF Deputy Director and Chief Operating Officer)
Dr. John Brighton*	Iowa State University, Vice Provost for Research (formerly NSF Assistant Director for Engineering)

Dr. Judith Cardell	Smith College, Assistant Professor of Computer Engineering
Dr. José Cruz	Ohio State University, Professor of Electrical and Computer Engineering
Dr. Ruth David	Analytic Services Inc., President and CEO
Dr. Eli Fromm*	Drexel University, Director of the Center for Educational Research in the College of Engineering, and Professor of Electrical and Computer Engineering
Dr. Kent Fuchs	Cornell University, Dean of Engineering
Dr. Don Giddens	Georgia Institute of Technology, Dean of the College of Engineering
Dr. Mary Good	University of Arkansas (Little Rock), Dean of the Donaghey College of Information Science and Systems Engineering
Dr. Jack Hansen	Florida Institute for Human and Machine Cognition, Associate Director
Dr. John Harwood	Pennsylvania State University, Senior Director of Teaching and Learning with Technology, and Associate Professor of Information Sciences and Technology
Dr. Ron Hira*	IEEE-USA, Vice President of Career Activities Rochester Institute of Technology, Assistant Professor of Public Policy
Dr. Susan Hockfield*	MIT, President
Mr. William Howard	CDM, Chief Technical Officer and Executive Vice President for Quality and Client Service
Dr. Leah Jamieson	Purdue University, Associate Dean of Engineering for Undergraduate Education, and Professor of Electrical and Computer Engineering
Ms. Gloria Jeff*	Michigan Department of Transportation, Director
Dr. Gretchen Kalonji	University of Washington, Professor of Materials Science and Engineering
Dr. Linda Katehi*	Purdue University, Dean of Engineering
Dr. Richard Larson	MIT, Professor of Civil and Environmental Engineering and Engineering Systems
Dr. Tod Laursen	Duke University, Senior Associate Dean for Education, Pratt School of Engineering
Dr. Thomas Litzinger	Pennsylvania State University, Professor of Mechanical Engineering, and Director of the Leonhard Center for the Enhancement of Engineering Education
Dr. Thomas Magnanti*	MIT, Dean of the School of Engineering
Dr. John H. Marburger III*	Office of Science and Technology Policy, Director, and Science Advisor to the President of the United States
Mr. Ray Mellado	HENAAC, Chair and CEO
Mr. James Miller*	Cisco, Vice President of Manufacturing Operations
Dr. Richard Miller*	Franklin W. Olin College of Engineering, President
Dr. Wendy Newstetter	Georgia Tech, Director of Learning Sciences Research in the Department of Biomedical Engineering

Dr. Peter Pao*	Raytheon Company, Corporate Vice President and Chief Technology Officer
Dr. Rassa Rassai	Northern Virginia Community College System, Professor of Engineering/ Electronics
Dr. Joseph Sussman	MIT, Professor of Civil and Environmental Engineering and Engineering Systems
Dr. Sophie Vandebroek	Xerox Corporation, Chief Engineer and Vice President of the Xerox Engineering Center

* Speaker/Moderator

A National Science Board-Sponsored Workshop

Moving Forward to Improve Engineering Education

November 7, 2006
The Georgia Institute of Technology

Summary Notes

The following summary notes of the discussions and presentations reflect the views and opinions of the participants and not necessarily the positions of the National Science Board.

A National Science Board-Sponsored Workshop

Moving Forward to Improve Engineering Education

Introduction

This report summarizes the key themes and suggestions resulting from the National Science Board (the Board)-sponsored workshop *Moving Forward to Improve Engineering Education*, held November 7, 2006 at the Georgia Institute of Technology (Georgia Tech). The 2006 Workshop followed the *initial* workshop held October 20, 2006 at the Massachusetts Institute of Technology *(*MIT*)*, entitled: *Engineering Workforce Issues and Engineering Education: What are the Linkages?* The 2006 Workshop engaged leading deans of engineering in elaborating on the issues and conclusions raised at MIT, and examined how programs and activities at the National Science Foundation (NSF) may specifically address the issues raised by the National Academy of Engineering (NAE) report, *Educating the Engineer of 2020.*[2]

The special focus of the second workshop on the role of NSF for engineering education addressed pressing issues in engineering education that included:

- Retention rates for students who enter universities to study engineering.
- Educational experience for engineering students that will prepare more well-rounded graduates who have skill sets to compete in a "flat world" economy.
- What the data on international engineering schools and graduates mean for American engineering programs, research, and careers, and how NSF can further develop cooperative research and joint programs between American and international universities.
- What NSF can contribute to an understanding of the social perceptions, the societal trends, and industrial practices that may discourage students from pursuing engineering.
- The role of the Foundation in preparing the faculty of the future, particularly given the need to educate engineering students more broadly and to address the challenges caused by rapid changes in technology.
- How the Foundation can facilitate the perspectives of industry in engineering education and encourage the support of industry for innovative approaches to engineering education.

To prepare for this second Workshop, Board Members met with NAE President, Dr. William A. Wulf, in August 2006 to discuss and understand NAE plans for following up on the Engineer of 2020 activity. The NAE will focus on the hard issues of curriculum reform across engineering education. It was agreed that the NSB can contribute with the NAE to a "tipping point" in engineering education by focusing on complimentary issues. Board Members also met with the leadership of the NSF Engineering Directorate in August to discuss NSF's current and potential role in engineering education and to consider possible issues for discussion at the workshop.

Key Themes

Several key themes emerged at the Georgia Tech workshop. First, NSF has made substantial investment in programs to improve engineering education over the last 2 decades, but these investments have been small relative to the overall scope of the challenge. There have been many successful programs and substantial local change, but not systematic change.

[2] *The Engineer of 2020: Visions of Engineering in the New Century, and Educating the Engineer of 2020: Adapting Engineering Education to the New Century.*

Second, retention of students in engineering, especially in the first year, is a critical issue. Many groups are analyzing the issue and trying to address it. It is necessary to approach the retention issue as a systems problem. That is, one has to include the pipeline as well as the cultural perceptions of engineering, from scientists to the public. The pre-college preparation of entering students affects retention, as does the difficulty of the engineering curriculum relative to other academic tracks especially relative to the perceived value. Some steps to improve engineering retention in the first year may make it more difficult for students to transfer into engineering in their second or third year. Differential minority retention is a problem requiring special attention. There are no simple solutions and hard work is needed in several areas, but a variety of approaches and NSF programs can help.

Third, there are many examples of programs in engineering schools that make engineering more attractive to students and provide the broader education (including international experience, engineering practice, leadership, and service) that is needed. A barrier is the limited amount of faculty time and faculty culture. Adjustments in the reward system for faculty and other changes, such as greater involvement of industrial fellows or greater support staff, can help.

Fourth, the problems regarding the perception – or misperception – of engineering are very serious. The public perception of engineering must change in order to attract more students to engineering. Over the last 20 years, medicine and law have wrestled with changing the public attitudes toward these fields and in attracting women and underrepresented minorities to pursue degrees and careers in these fields. Similar changes need to occur in engineering, but much hard work will be required to convey the proper image and value of engineering to students, parents, guidance counselors, and others.

The following sections summarize the key points that were made with respect to each of these themes.

Summary of Key Points and Suggestions

Review of Previous and Current National Science Foundation Programs

NSF has supported a wide range of activities that contribute to engineering education. These include:

- Engineering Education Coalitions focused on broad reforms. Coalition members obtained local improvements, such as improved retention rates for first-year students and underrepresented groups. The coalitions, however, did not lead to the comprehensive and systematic new models for engineering reform that were expected.
- Engineering's department-level reform program supported departments to comprehensively reform curricula.
- Investments in curriculum improvement, with both planning and implementation grants.
- Engineering Research Centers, leading to many new degree programs and curricula, and to graduates whom companies recognize as better prepared for the practice of engineering.
- Model Institutions of Excellence focused on increasing the number of undergraduate minorities graduating in all areas of science, math, and engineering. The program has increased grade point averages (GPAs) and graduation rates of minority students.
- Centers for Teaching and Learning address learning and teaching across the fields of science, math, and engineering, and how to prepare future faculty.
- Graduate Fellowships and Traineeships include a variety of different fellowships and training programs, including Integrative Graduate Education and Research Traineeship (IGERT), Graduate Teaching Fellows in K-12 Education (GK-12), and Graduate Research Fellowships.
- Research Experiences for Undergraduates (REU) encourages U.S. students to pursue doctoral studies by engaging them in research activities as undergraduates. Studies have shown that REU experiences increase interest in science, technology, engineering, and mathematics (STEM) careers.

- Research Experiences of Teachers (RET) supports K-12 teachers and community college faculty to be involved in research activities at universities. Studies indicate that RET experiences increase teacher motivation and confidence in teaching math and science, and that teachers gain a better understanding of engineering.

In summary, NSF has made significant investments in activities related to engineering education, and many of these programs show positive results and change at institutions. However, the complexity of the system does not allow for quick and easy solutions. Still, greater success is needed to increase U.S. citizen participation in engineering studies and careers.

Retention

There was widespread agreement among workshop participants that retention of engineering students is a key issue. There is substantial attrition in engineering, especially in the first year. Most of the students who leave engineering continue in college but change their major. Attrition is higher among women and traditionally underrepresented minorities.

Reasons Why Engineering Students Leave

Some of the students who leave engineering are among the best students, with high grades. That is, it is not the case in general that students who leave engineering could not have made it. Those with high verbal SATs are more likely to leave than those with lower verbal scores, perhaps because they have more options. Also, women with good grades drop out at a higher rate than men. There are many reasons why students drop out of engineering. Some of the key reasons discussed at the workshop are:

- Poor teaching – which when combined with a lack of exposure to engineering in the first and second years can lead to discouragement and departure from engineering.
- Poor performance in the first math courses.
- Poor advising from faculty who see their role as weeding people out of engineering.
- Lack of connection between what students study and what they perceive as exciting engineering practice.
- Fear that engineering jobs may disappear in the United States due to offshore outsourcing.
- Perception that friends in other majors are having easier classes and more fun.
- Coursework too restrictive for students' more varied interests.
- Lack of a comfortable social environment in engineering classes.
- Perception of engineering as a competitive and uncaring field.
- Lack of role models, especially for women and underrepresented minority engineers. Many students see women and underrepresented minority faculty as overworked because of the challenges they face as pioneers. Thus, students do not find models of what they want to be.
- Rising cost of education – tuition, fees, room and board – which has a disproportionate impact on students from low income families.
- A feeling of isolation from the rest of the university due to amount of the workload. Engineering students without cross-disciplinary education may not see themselves as part of the university.

Participants in discussion of these issues recognized the need for caution in interpreting the reasons that students give for leaving engineering. For example, poor math performance has diverse causes. Some students are under-prepared when they enter college. Others are rusty in their basic math skills because they take advanced math earlier in high school, and may not take math in their last year of high school. Some students are overconfident, and are either placed in a college math course that is too advanced or skip classes because they think they know the math. Students may not be willing to admit they are leaving because they do not have the talent for engineering or do not want to work hard. Students do not perceive the value of working hard in engineering classes.

Programs That Improve Retention

Getting students through the first year is critical. To do this, it is important to approach retention as a systems problem. Addressing the issue requires starting with students before they come to campus and then engaging the whole university.

A major strategy for improving retention is to design a curriculum that offers the excitement and relevance of engineering early in the student's experience and, therefore, accelerates the student's ability to identify with the profession of engineering. There are many successful approaches:

- Moving design and systems courses and practical engineering laboratories earlier in the curriculum rather than waiting until the junior or senior year, by which time many students have already left engineering. This of course means changes in the traditional cumulative practice of engineering education.
- Offering a socially relevant curriculum that emphasizes service learning; a strategy especially attractive to underrepresented groups and women.
- Providing a first-year seminar on what engineering is, with examples from each discipline and discussions of engineering problems and applications led by invited engineering practitioners.
- Having a weekly symposium with speakers from industry.
- Inviting industry partners to work on team projects.
- Developing multi-year team-based projects that involve participants from other disciplines (sciences, humanities, social sciences).
- Working with math and physics professors to add engineering context to math and physics courses.
- Introducing undergraduate research experience as early as possible to students.
- Financial aid for students who have demonstrated need.
- Cooperative education.
- Intervention programs that address academic preparation and performance issues.

To address the problems associated with poor math preparation, it is important to do early assessment in math courses and to make available extra resources for students who need them – the University of Texas, El Paso (UTEP) was mentioned as a model, including math diagnostics, remediation, and clustering students in classes and study groups. It was noted that a successful strategy in computer programming separates students with no prior programming background from those with extensive programming background.

Workshop participants emphasized the importance of working with other units in the university to improve the educational and social environment for engineering. The sciences are responsible for teaching many of the fundamental courses in the engineering curriculum; interaction between faculty in engineering and faculty in the arts and social sciences can help put engineering in a social or business context. In addition, it is important that engineering students do not become isolated from the rest of the university. They need exposure to different disciplines to help them decide their major and career path or to give them the necessary career clarity.

To address issues of affordability, more need-based scholarships were considered necessary. Moreover, universities should develop and maintain good partnerships with community colleges to ensure their courses provide the right preparation for engineering. Two-year colleges provide a pathway for less affluent students to enter engineering and can help increase minority participation in engineering. Transfer students from community colleges have a good record of completing degrees after transferring to an engineering school.

Flexibility in the curriculum is important for people to transfer into engineering after the freshman year. It was cautioned that if more engineering courses are moved into the first and second years of a university engineering program, it might be more difficult for transferring students, either from community colleges or from other majors.

Diverse role models and mentoring have been effective in improving retention. Student organizations can play a part by bringing in role models as speakers or mentors. Peer-to-peer advising (pairing upper division students with new students) also has been especially helpful.

Research experiences too can help improve retention; it would be beneficial to provide more exposure to research in the earlier years. Research experiences expose students to the challenge of solving ambiguous problems in a setting where they interact with a faculty member.

The Educational Experience of Engineering Students

Workshop participants described a wide range of programs that enhance the educational experiences of students, especially with regard to preparing students for the "flat world paradigm" in which the research, design, and production of goods and services are often sourced around the world in response to market forces. These programs are intended to prepare engineering students to be aware of the world, technically grounded, creative, innovative, and versatile; to develop leadership skills; and to work effectively in teams.

Approaches

Since traditional curricula are so full, it is difficult to add traditional courses to the curriculum. Thus it may be necessary instead to integrate experiences throughout the curriculum and extracurricular activities. Experiential learning can take place in many forms (in the curriculum, non-curricular activities, coop programs, and internships); can motivate student learning in the fundamentals; and can create opportunities to bring design and analysis together, rather than segregating design and analysis. There is also a need to create long-term experiences, such as projects that span years and make connections between different skills and applications. Students working on open-ended projects under expert mentoring will learn unanticipated things. Another topic is how to modify the educational experience to provide global educational opportunities.

Participants identified a range of programs or extracurricular activities to provide international experiences:

- Study abroad programs, which are increasingly recognized as valuable for engineering.
- Classes with an international focus, such as an "engineering in China" seminar.
- A global design course, in which students interact on teams with students from other countries for a semester.
- A course on innovative design, entrepreneurship, and leadership, co-taught by industry practitioners, and involving cross-national teams with international clients.
- A global engineering internship program that places students in other countries for the summer.

Some programs change the traditional paradigm and put design at the center of the curriculum and applied science around the edge, rather than vice versa. Design courses serve to identify gaps in student knowledge and in the curriculum. Other programs emphasize service learning, such as volunteer leadership. One example is an engineering leadership development minor. Other programs focus on entrepreneurship. Some schools have an engineering entrepreneurship minor while others have entrepreneurship embedded throughout the curriculum and extracurricular activities. Kauffman Foundation programs in entrepreneurship provide examples of weaving entrepreneurship throughout the entire curriculum rather than narrowly embedding it in the business school.

Research experiences for undergraduates, including freshmen and sophomores, was also recognized as an effective program for getting students to understand the joys of engineering while broadening their education. These experiences also bring the students into contact with the faculty.

Professional societies, such as student chapters of the Institute of Electrical and Electronics Engineers, Inc. (IEEE), and other student activities are also important. They can build on relations with industry to provide lecturers, mentors, internships, and award programs.

Challenges

Participants identified a number of challenges for reform of engineering education. One challenge is assessment – how does one measure the learning that occurs in nontraditional settings where each student's experience is different? For example, how does one assure that leadership training is effective? Engineering schools may need to adopt a portfolio approach to assessment, which is common in the arts but not in engineering.

Another challenge relates to accreditation and professional engineering (PE) licensing. It is not possible to teach everything that students need to learn. A key issue is: What do students need to know, and what can be pared back to make room for new material? How will accrediting and licensing bodies view such changes? Professional engineering exams may need to be modified.

Concern was expressed about proposals to require additional credit hours beyond the BS degree before an individual can take the PE exam, with potential negative impacts on attracting students to engineering if certification requires a master's degree.

Another challenge is the increased burden that many of the activities for enriching the engineering education experience would place on faculty. Faculty members have a finite amount of time, and if they devote more time to these kinds of activities, what can get dropped from their workload? The issue is the culture of academic engineering which emphasizes research, teaching, and service, in that order. Workshop participants offered several suggestions for addressing the issue of faculty time:

- Get industry involved to provide advisors on a pro bono basis.
- Use engineers recently retired from industry as "Professors of Practice."
- Use upper-class students for assistance in classes and extracurricular activities.
- Hire facilitators/assistants to complete administrative work that faculty do not need to do.
- Conduct a review of how faculty spend their time to see if time can be freed up.
- Submit proposals for funding to do innovative things.
- Ask the college administration to define goals for each department, but let the department decide how to meet the goals – by distributing research, teaching, and service activities among the faculty, considering faculty members' interests and priorities at different stages of their careers.

Engineering Perceptions

Common Perceptions of Engineering

Engineering loses students because they cannot see themselves as engineers. There are major problems with the way engineering is perceived. Survey data indicate that the public associates engineers with economic growth and defense, but less so with social concerns such as improving health, the quality of life, or the environment. Outside of academic institutions, engineers are commonly perceived as nerds without personal skills, doing narrowly focused jobs that are prone to being outsourced. A recent widely circulated Dilbert cartoon emphasized the notion that engineers are without social skill. In addition, students do not understand or appreciate the use of an engineering education as a springboard into other fields.

High school girls believe engineering is just for people who love math and science, and just for guys. They do not have an understanding of what engineering is or show an interest in the field. At historically black colleges and universities (HBCUs), students see engineering as unfriendly, hard, difficult to afford, and requiring extra preparation. They may not see a direct benefit to their community and may believe that they would have to leave their community to succeed in an engineering career.

Such perceptions attract to engineering the people who are good in math and science and are interested in "things" rather than people, but not people with creativity who like to work with others on teams and who want to contribute to solving social problems. The current perceptions of engineering make it difficult to attract women and minority students, in particular, to the field. It has been shown, however, that when students learn more about engineering, especially its historical contributions as well as its social relevance, they react more positively about the field.

Solutions

Engineering needs a marketing facelift. There is a need to craft messages that will attract students, parents, counselors, and teachers. The messages should emphasize that engineers work in teams, create jobs and value, are global innovators and leaders, and start companies like Intel, Yahoo!, and Google as well as Boeing and Hewlett Packard. Engineering graduates succeed in many fields, from investment banking to medicine, and engineers will play a role in addressing the world's biggest problems, from global warming to poverty to nuclear proliferation. Engineers create cool devices like Xboxes and iPods. Opportunities to learn from business schools and medical schools were acknowledged. Business schools have a fully integrated project-based learning program. Both medical schools and business schools have succeeded in transforming their culture from 100 percent male to 50:50 male/female.

The NAE is supporting the development of themes to communicate the role, importance, and career potential of engineering to a variety of audiences. Some sample themes being tested include:

- Limitless imagination – engineers imagine things and see possibilities.
- Freedom to explore – engineers are never bored; they are constantly being challenged.
- Ideas in action.
- Life involves engineering, from medical equipment to safer water to microchips.

The messages should be targeted to specific fields. Concerns about offshore outsourcing mostly affect computer science. Some fields of engineering, such as bioengineering and environmental engineering, already attract many women, whereas other fields have a dearth of female engineering students.

Workshop participants offered a variety of concrete suggestions that could help improve the image of engineering:

- Work with the Nobel Prize committee to create a Nobel Prize for engineering. While there are existing large prizes for engineering (such as the NAE's Charles Stark Draper Prize), none as yet have the visibility of the Nobel Prizes or the Oscars.
- Work with Fortune 500 CEOs who are engineering graduates to put together ad campaigns that will affect both perceptions of the engineering community and their company.
- Support industry-community-university partnerships that inform pre-college students and parents about engineering. K-12 schools are a particularly important venue for changing the views of students about engineering. The Research Experiences for Teachers (RET) program can contribute much to changing perceptions.
- Have college engineering students do internships in K-12 that will provide role models for K-12 kids.
- Teach engineering in high school. The high school engineering curriculum developed through the Infinity project at Southern Michigan University (*http://vab.infinity-project.org/home.html*) and coursework developed by the Boston Museum of Science have been successful. Some concern was expressed, though, that high school engineering classes may not meet the current science requirements for entrance to college engineering courses.
- Develop more movies (e.g., "October Sky") and TV shows to present engineering in a positive light. Shows like "Pimp My Ride" on MTV provide ways to talk about engineering to students.
- Find spokespersons to whom high school students can relate.

Suggestions for NSF

The workshop generated a large number of specific suggestions for NSF. Many of these involved support for continuing and expanding existing programs. These include:

- Substantially expand the REU program to make it more available to college freshmen and sophomores, as well as to community college and even high school students. (A few REU sites are already open to college freshmen and sophomores and to community college students.)
- Explore expanding REU to include support from additional Federal agencies. There is already a partnership with the Department of Defense (DoD), which supports REU Sites in DoD-relevant research areas. This could be expanded to the National Aeronautics and Space Administration (NASA), the Departments of Energy, Transportation, Agriculture, and others.
- Provide a path for REU students to get fellowships for graduate school. Tie this to strong mentoring in this direction.
- Expand the RET program. Provide opportunities to keep teachers connected to the program.
- Expand support for the GK-12 program.
- Expand the Integrative Graduate Education and Research Traineeship (IGERT) concept to the undergraduate level with a focus on integrative engineering.
- Build on IGERT to create a broader program "ISEAHSS" (Interdisciplinary Studies in Engineering, Arts, and 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.
- Continue the ADVANCE program (Increasing the Participation and Advancement of Women in Academic Science and Engineering Careers),[3] and create a similar program focused on developing the minority professoriate.
- Expand full-ride scholarships, which are important to all students but especially minority students.
- Continue to support engineering education research and experimentation, in order to create a scholarship of engineering education. NSF should also expand dissemination of engineering education best practices through a database and Web site that would provide details on successful programs and lessons learned.

There were also a variety of suggestions for new activities:

- NSF could examine and leverage the success of various design competition programs, such as the For Inspiration and Recognition of Science and Technology (FIRST) robotics competitions (*www.usfirst.org*) and the Sally Ride Science Toy Challenge (*www.toychallenge.com*). NSF could review these programs and determine if there is a role for NSF to help support them, expand them to allow broader participation, or fill gaps in the programs (such as making them relate to different types of engineering or appeal to different demographic groups).
- NSF could focus attention and programs on the complete U.S. engineering pipeline, K-12 through Ph.D., through research experiences, with an emphasis on helping students make the transition to the next stage. The community college-engineering school transition deserves special attention. The Facilitating Academic Careers in Engineering and Science (FACES) program at Georgia Tech, which supports students to continue to the next level, is a model.
- NSF could state national 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 was acknowledged, however, that this might be difficult to do and might invite blame to be put on NSF for engineering shortages or surpluses. However, NSF should be visible on this.
- The NSF Directorates of Education and Human Resources (EHR), Mathematics and Physical Sciences (MPS), and Engineering (ENG) could collaborate to introduce an application-oriented capstone math program with engineering connections for senior high school students.
- The Board Chairman should ask the Commission on 21st Century Education in STEM to address the role of engineering education in high school.

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[3] *ADVANCE includes Institutional Transformation Awards, Leadership Awards, and Partnerships for Adaptation, Implementation, and Dissemination Awards, to advance women in academic science and engineering careers.*

- NSF could sponsor workshops to heighten awareness, exchange ideas, encourage implementation, and share practices. Examples might include mentoring and how to incorporate non-technical skills, such as ethics, in technical courses. NSF could also sponsor workshops that draw together high school guidance counselors and math and science teachers to exchange information regarding the career messages they are providing to students. This allows high school counselors to be well-informed and provide better guidance.
- NSF should look to minority-serving institutions (MSI) for leadership in broadening participation. NSF should engage MSIs for research on recruitment, preparation, and retention.
- NSF could provide support for programs that fund cross-disciplinary education and seminars, such as symposia that would focus on the intersection of technology and the economy.
- NSF could support international programs in engineering schools by collecting data on universities with programs overseas, and perhaps providing support for students who otherwise would not have the resources to participate in such programs.
- NSF and industry can support educational programs to address the perceptions issues in engineering. These programs should deal with the realities of how industry handles jobs and career stability issues.

Summary and Conclusions

The workshop focused on the issues faced by deans of engineering in reforming engineering education, primarily in three areas: (1) retention rates in engineering undergraduate programs; (2) the educational experience of engineering students; and (3) the public perception of engineering.

Participants showed general agreement on the changing context of engineering and the challenges facing engineering education. There also seemed to be general agreement, or a least a lack of disagreement, on most of the points made regarding the benefits or effectiveness of most of the programs and solutions discussed. There was agreement on the importance of retention in the first year of college, but some disagreement on the reasons for high attrition from engineering. While students may state that they leave engineering because of poor teaching, participants noted that early courses are often taught in science and mathematics departments, rather than engineering. Some suggested that students may blame the teaching when the real reason may be that students do not have talent for engineering or do not want to work hard. Underlying disagreement about causes of attrition may be associated with disagreement about what skills and traits are necessary for engineers, e.g., are strength in math and science fundamental to success in engineering, or should students who are not as strong in math and science but are creative, socially engaged, and good communicators also be retained in engineering?

With regard to the educational experience of engineering students, workshop participants seemed to be in general agreement on the desirability of providing a broader engineering educational experience. Several alternative general approaches to this were discussed, including:

- Dropping some of the existing traditional engineering curriculum (e.g., Fourier transforms) in favor of material related to soft skills such as communication, leadership, and entrepreneurship, etc.. This would have to be done in concert with graduate schools and employers.
- Embedding social and global context, leadership, and other broader skills as themes throughout the curriculum.
- Developing extra skills through extracurricular activities, rather than through the curriculum.
- Completely revising the curriculum, with design and student engagement at the center.
- Adding courses to the curriculum to make, in effect, the master's degree become the professional degree.

Each approach was seen as having some drawbacks, and there was no consensus on a best approach. Revising the curriculum with design at the center and with a focus on student engagement was viewed as impractical for large schools. This approach, as well as adding extracurricular activities, was seen as putting a large burden on faculty time. While there seemed to be a benefit to having universities use different or multiple approaches, participants recognized that reforms must take into account standards set by accrediting and licensing organizations for engineers. With regard to a proposal to require a master's degree for professional certification, participants expressed great concern that the additional hurdle would result in a decline in student interest in engineering.

There seemed to be consensus on the problems with the way engineering is perceived. There also seemed to be widespread agreement on appropriate solutions, which involved developing and communicating new messages about the excitement and value of engineering to students, parents, counselors, and teachers. Ad campaigns, internship experiences for students and teachers, and the mass media could be helpful in spreading positive messages about and deepening public understanding of engineering. There was discussion about the need to target messages to focus on specific fields that are having greater difficulty than others in attracting underrepresented populations or because some of the concerns about engineering, such as offshore outsourcing, affect only specific fields.

Many suggestions were made to expand or add to NSF programs. Although participants did not prioritize proposals, expanding the REU and IGERT programs and extending to make these programs available to younger students, even in high school, received strong support, as well as modifying the RET program to provide a way to keep teachers connected to the program after they return to their schools. There also was strong support for expanding financial support for engineering students and continued engineering education research and experimentation, combined with a database and Web site that would be easy to access and provide details on successful programs and lessons learned. It was also recommended that NSF sponsor workshops to improve engineering education, including discipline-specific workshops on incorporating soft skills into technical coursework and to heighten awareness of the importance of mentoring, especially by students. NSF also could be effective in raising awareness of math and science teachers and guidance counselors about engineering education and careers to help change public perceptions. There also seemed to be wide support for NSF to explore ways to support or expand engineering design competitions as a way of exciting students about engineering. Participants acknowledged that NSF cannot have sufficient impact acting alone, and that the National Science Board might undertake a role to involve more Federal agencies that employ engineers to help expand successful programs.

In sum, participants agreed on the need for engineering education reform and on very broad cooperation to be successful. The NSF was seen in a supportive role, through leadership in the Federal sector, increased development and dissemination of research-based scholarship on engineering education, expanded student financial support, support for programs that involve students and teachers in research and in broader experiences outside the scope of traditional disciplinary education, and outreach activities to generate greater public and student understanding and excitement about engineering.

National Science Board Workshop

Moving Forward to Improve Engineering Education

Georgia Institute of Technology

Monday, November 6, 2006

7:00 p.m. Reception and Registration

Tuesday, November 7, 2006

8:30 a.m. **Welcome**

Steven C. Beering, Chairman, National Science Board

G. Wayne Clough, President, Georgia Institute of Technology

8:45 a.m. **Overview of the Workshop and Self-Introductions of Participants**

Michael P. Crosby, Executive Officer, National Science Board

9:00 a.m. **Summary of the October 20, 2006 National Science Board sponsored workshop, *Engineering Workforce Issues and Engineering Education: What are the Linkages?***

Daniel E. Hastings, National Science Board

9:15 a.m. **Review of Previous and Current National Science Foundation (NSF) Programs and Activities in Engineering Education**

Richard O. Buckius, National Science Foundation

9:30 a.m. **Panel 1: Retention Rates in Engineering Undergraduate Programs**

Moderator: Dr. Clough, National Science Board

What is the role of the Foundation in understanding the issues associated with retention of students who enter universities to study engineering and in developing approaches to address these challenges?

Ilesanmi Adesida
University of Illinois at Urbana-Champaign

Esin Gulari
Clemson University

Kristina M. Johnson
Duke University

10:00 a.m. Group Discussion among Workshop Participants

10:30 a.m. Questions and Comments from the Audience

10:45 a.m. **Break**

11:00 a.m. **Panel 2: The Educational Experience of Engineering Students**

Moderator: Dr. Hastings, National Science Board

What is the best way to create an educational experience for an engineering student that will allow for more well rounded graduates who have skill sets that will allow them to compete in a "flat world" economy? How may co-op and internship programs, student professional societies, volunteer activities, student government, and/or study abroad programs contribute to the educational experience of engineering students? How may larger university environments best leverage opportunities for engineering students? Is there a unique role for NSF in supporting the efforts of colleges and universities to enhance the educational experience of engineering students? How can larger university environments be used to leverage opportunities for engineering students?

Leah H. Jamieson
Purdue University

Richard Miller
Olin College of Engineering

David N. Wormley
The Pennsylvania State University

11:30 a.m. Group Discussion among Workshop Participants

12:00 noon Questions and Comments from the Audience

12:15 p.m. **Lunch**

Speaker: Bryan Moss, President, Gulfstream Aerospace

1:30 p.m. **Panel 3: Engineering Perceptions**

Moderator: Louis J. Lanzerotti, National Science Board

What can NSF contribute to an understanding of the societal trends and industrial practices that may discourage students from pursuing engineering?

Don Giddens
Georgia Tech

Eric J. Sheppard
Hampton University

Belle Wei
San Jose State University

2:00 p.m. Group Discussion among Workshop Participants

2:30 p.m. Questions and Comments from the Audience

2:45 p.m. **Break**

3:00 p.m. **Breakout Sessions**

Session Chairs: Drs. Clough, Hastings, and Lanzerotti

How can NSF assist in moving the agenda forward on engineering education reform and address the issues of retention rates, educational experience, and engineering perceptions?

4:30 p.m. **Reports From Breakout Groups**

4:45 p.m. **Roundtable Discussion among Workshop Participants**

Moderator: Dr. Hastings

5:15 p.m. **Summary of Major Findings and Conclusions**

National Science Board-Sponsored Workshop

Moving Forward to Improve Engineering Education

Georgia Institute of Technology
Atlanta, Georgia
November 7, 2006

Invited Workshop Participants

Participant	Affiliation
	National Science Board
Dr. Steven C. Beering	NSB Chairman
Dr. G. Wayne Clough	NSB Member
Dr. Patricia D. Galloway	NSB Member
Dr. Daniel E. Hastings	NSB Member
Dr. Elizabeth Hoffman	NSB Member
Dr. Louis J. Lanzerotti	NSB Member
Dr. Michael P. Crosby	NSB Executive Officer
	National Science Foundation
Dr. Richard O. Buckius	NSF Assistant Director for Engineering
	Participants
Dr. Ilesanmi Adesida	University of Illinois at Urbana-Champaign, Dean, College of Engineering
Dr. William Baeslack III	The Ohio State University, Dean, College of Engineering
Dr. Joseph Barba	The City College of New York, Dean, The Grove School of Engineering
Dr. P. Barry Butler	The University of Iowa, Dean, College of Engineering
Dr. Steven L. Crouch	University of Minnesota, Dean, Institute of Technology
Dr. Eugene M. DeLoatch	Morgan State University, Dean, School of Engineering
Dr. Don Giddens	Georgia Institute of Technology, Dean, College of Engineering
Dr. Esin Gulari	Clemson University, Dean of Engineering and Science
Dr. Laura Huenneke	Northern Arizona University, Dean, College of Engineering and Natural Sciences
Dr. Leah H. Jamieson	Purdue University, John A. Edwardson Dean of Engineering
Dr. Kristina M. Johnson	Duke University, Professor and Dean, Pratt School of Engineering

Dr. Richard K. Miller	Olin College, President
Dr. David C. Munson, Jr.	University of Michigan, Robert J. Vlasic Dean of Engineering
Dr. Kevin J. Parker	University of Rochester, Dean, School of Engineering and Applied Sciences
Dr. Paul S. Peercy	University of Wisconsin-Madison, Dean, College of Engineering
Dr. James D. Plummer	Stanford University, Frederick Emmons Terman Dean of the School of Engineering
Dr. John R. Schuring	New Jersey Institute of Technology, Dean, Newark College of Engineering
Dr. Eric J. Sheppard	Hampton University, Dean, School of Engineering and Technology
Dr. Stephen W. Stafford	The University of Texas at El Paso, Dean, College of Engineering
Dr. Ben G. Streetman	The University of Texas at Austin, Professor and Dean, College of Engineering
Dr. Satish S. Upda	Michigan State University, Dean, College of Engineering
Dr. Belle W. Y. Wei	San Jose State University, Dean, College of Engineering
Dr. David N. Wormley	Pennsylvania State University, Dean of Engineering
	Lunch Speaker
Mr. Bryan Moss	President, Gulfstream Aerospace

NSB-05-41
Approved March 30, 2005

Committee on Education and Human Resources Workshop on Engineering Workforce Issues and Engineering Education: What are the Linkages?

Purpose
An initial, single day NSB-sponsored workshop is proposed to focus on recent recommendations for changes in engineering education and implications for the engineering workforce. A foundation for workshop discussions will include the cross cutting issues in the recent National Academy of Engineering report, *The Engineer of 2020: Visions of Engineering in the New Century,* as well as the NSB reports that identified troublesome trends in the number of domestic engineering students, with potential impacts to U.S. preeminence in S&E based innovation and discovery. The major workshop objective is to move the national conversation on these issues forward in a productive way by calling attention to how engineering education must change in light of the changing workforce demographics and needs. The National Academy of Engineering (NAE), which sponsored the Engineer of 2020 study, has undertaken a Phase II study. The proposed NSB workshop would be in parallel to these NAE efforts. The NSB workshop would focus more substantially on the issues of the current and desired future engineering workforce in light of the Engineer of 2020 report.

Statutory basis
NATIONAL SCIENCE BOARD (42 U.S.C. Section 1863) SEC. 4 (j) (2) The Board shall render to the President for submission to the Congress reports on specific, individual policy matters related to science and engineering and education in science and engineering, as the Board, the President, or the Congress determines the need for such reports.

Link to National or NSF Policy Objective
It is widely recognized that our economy, national security, and indeed our everyday lives are increasingly dependent on scientific and technical innovation. Changes on a global scale are rapidly occurring for engineering, and Federal leadership is needed to respond quickly and informatively. The Board has issued several reports expressing concern about long-term trends that affect the 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 education system; and demographic trends that are unfavorable to increasing citizen participation rates in these fields. Engineers are the largest component of workers with college degrees in S&E occupations, with 39 percent of all S&E occupations in 1999. Almost half of S&Es in the labor force with bachelors' degrees as their highest-level degree are engineers. This field therefore has a huge impact on our national capabilities for S&T and deserves special attention.

There is a current high level of attention to engineering education from a variety of sources that converge to make engineering education an especially timely topic for the Board to address. These include the recent release of the National Academy of Engineering report, *The Engineer of 2020: Visions of Engineering in the New Century*, which calls for reform in engineering education; the National Science Board reports on unfavorable trends affecting long-term U.S. workforce capabilities in science and engineering and the need to address these trends along all points of the education pipeline; the concern of U.S. industry and the public sector in engineering capabilities in the workforce; and the poor progress in broadening participation in engineering.

Logistics
The NSB Office will be the focal point for providing all aspects of Board support in this NSB activity; coordinating NSF, other agencies and institutions involvement; and utilization of one or more NSB Office contractual agreement(s) to assist with meeting logistics. NSB/EHR will recommend full Board approval of the appointment of an *ad hoc* Task Group of EHR to provide oversight for, and actively engage in, this activity.

An agenda and a comprehensive list of potential participants in the event will be developed with input from Board Members, NSF management, contacts in other agencies, and the broader S&T research and industry community. Invitees would include young recently graduated engineers, more experienced engineers, a range of employers (spanning the range of engineering disciplines), university thought leaders on engineering, and experts on engineering demographics.

Timing: Fall/Winter 2005

Workshop Topics: A workshop on the linkages between workforce issues and engineering education would involve a large range of topics, such as:

1. What are different scenarios for engineering workforce development in the U.S.? What are the differences among engineering fields?
2. How successful have we been in predicting the engineering workforce needs in the past and what has happened to the engineers when we got it wrong?
3. What are the implications of the different scenarios for engineering education?
4. What are the roles of the different stakeholders in the development of the engineering workforce, particularly the professional societies, universities, working engineers (of differing ages) and employers?
5. What is a typical demographic for an engineer today, and what will it become? How do we broaden participation?
6. The past and future role of international students and engineers in the U.S. engineering workforce.
7. The changing role of engineering education in preparing for engineering workforce needs for the future, including graduate education and lifelong learning as career shifts occur, and the idea that engineering education might be to prepare students more broadly for employment in the public, nonprofit, academic, and industry sectors.
8. How do we ensure that the best and the brightest students pursue engineering studies and careers, and that their education quality, content, and teaching are of the highest caliber?

Workshop Product: The final output from the meeting will be a concise set of Board approved recommendations that tie back to what universities (with employers) and NSF can affect, published in paper and electronic formats.

Audiences: In addition to the President, Congress, and NSF:

- Engineering deans/departments/schools
- ABET
- Engineering thought leaders

Leaders in technical industry and the public sector that employ engineers.

Moving Forward to Improve Engineering Education

Workplan for a National Science Board Sponsored Workshop on Engineering Education November 7, 2006

With the support of the National Science Board (the Board) Committee on Education and Human Resources (EHR), the ad hoc group composed of Drs. G. Wayne Clough, Daniel E. Hastings, and Louis J. Lanzerotti have moved forward with plans for a second engineering education workshop to follow-up on the workshop held October 20, 2006 at MIT, entitled: Engineering Workforce Issues and Engineering Education: What are the Linkages? This follow-up workshop, scheduled for November 7, 2006 at Georgia Institute of Technology, will engage leading deans of engineering and elaborate on the issues raised at MIT, and examine how programs and activities at the National Science Foundation (NSF) may specifically address the issues raised by the National Academy of Engineering (NAE) Educating the Engineer of 2020 report.

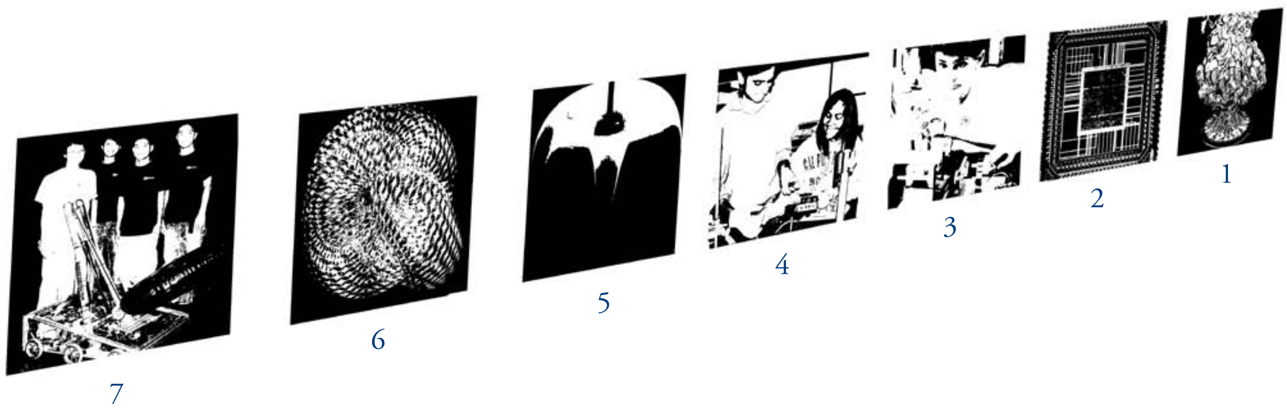
NSF is an important leadership agency for engineering education and needs to respond to pressing issues, including retention rates, the educational experience of engineering students, international education and workforce issues, the current perception of engineering, the faculty of the future, and the perspective of industry.

- Retention Rates: What is the role of the Foundation in understanding the issues associated with retention of students who enter universities to study engineering and in developing approaches to address these challenges?
- Educational Experience: What is the best way to create an educational experience for an engineering student that will allow for more well rounded graduates who have skill sets that will allow them to compete in a "flat world" economy? How may co-op and internship programs, student professional societies, volunteer activities, student government, and/or study abroad programs contribute to the educational experience of engineering students? Is there a unique role for NSF in supporting the efforts of colleges and universities to enhance the educational experience of engineering students?
- International Perspective: In a broad sense, what do the data on international engineering schools and graduates mean for American engineering programs, research, and careers? How can NSF further develop cooperative research and joint programs between American and international universities?
- Engineering Perceptions: What can NSF contribute to an understanding of the societal trends and industrial practices that may discourage students from pursuing engineering?
- Engineering Faculty: What is the role of the Foundation in preparing the faculty of the future, particularly given the need to educate engineering students more broadly and to address the challenges caused by rapid changes in technology?
- Industrial Perspective: How can the Foundation facilitate the consideration of the perspective of industry, and to encourage the support of industry, for innovative approaches to engineering education?

To prepare for this second activity, the *ad hoc* engineering education group will meet with NAE President, Dr. William A. Wulf, in August to discuss what the Academy plans to do following the Engineer of 2020 activity. The *ad hoc* group will also meet with the leadership of the NSF Engineering Directorate in an informal roundtable discussion in August to discuss NSF's current and potential role in engineering education and consider possible issues for discussion at the fall workshop.

After this second workshop, the engineering education group plans to submit a draft report of both workshops, which could potentially be submitted to the full Board to consider issuing some recommendations to guide engineering education reform.

Cover Captions and Credits



1. Computational Fluid Dynamics

This graphic depicts the turbulent instability dynamics of large fire plumes, which have been modeled by Paul DesJardin, Department of Mechanical and Aerospace Engineering, on the University at Buffalo's Center for Computational Research (CCR) computers using Large Eddy Simulation techniques. The research was supported by an NSF Career Award to Professor DesJardin. Instability dynamics are responsible for the unsteady heat transfer in fire environments, which have been observed experimentally. The mesh superimposed on the bottom of the plume is the underlying computational grid utilized to carry out the calculation. An improved understanding of instability dynamics will result in more accurate predictions of fire intensity and growth.

Credit: Paul DesJardin, Department of Mechanical and Aerospace Engineering, University at Buffalo; visualization by Adam Koniak, CCR, University at Buffalo

2. Systems-on-a-Chip for Powerful Prostheses

A novel, mixed-signal system on a chip as a platform for implantable prosthetic devices, developed at the University of Southern California's Center for Biomimetic MicroElectronic Systems (BMES) Engineering Research Center (ERC). Researchers at BMES ERC, an NSF centers program, are developing entire platforms for a range of implantable devices that could one day restore vision to the blind, reanimate paralyzed limbs, and overcome certain cognitive impairments.

Credit: University of Southern California, BMES ERC

3. PIE Institute

A "Playful Invention and Exploration (PIE) Institute" Mindfest visitor constructs automata using gears, Legos, found materials, and a Cricket computer. The PIE Institute is a 3-year project designed to increase the capacity of museum educators and exhibitors to design and implement technology-integrated inquiry activities for the public. The collaborators include the San Francisco Exploratorium, the Massachusetts Institute of Technology Media Lab, the Science Museum of Minnesota, the Fort Worth Museum of Science and History, and the Explora Science Center and the Children's Museum of Albuquerque. Participating centers and museums will receive technology-rich activities, professional development institutes, online educator resources, and a handbook of pedagogical design principles for museum educators. The project builds upon prior NSF-supported work that developed the PIE Network, which among other things developed the "cricket," an inexpensive computer that makes informal learning inquiry activities more compelling.

Credit: Karen Wilkinson, Exploratorium, San Francisco

4. BMES REU Program

Research Experiences for Undergraduates 2004 participant, Brittney Perry, at the Biomimetic MicroElectronic Systems (MBES) Engineering Research Center (ERC), with mentor Ashish Ahuja, is shown working in Armand Tanguay's laboratory at the University of Southern California, Los Angeles. BMES ERC offers a summer program for undergraduate students funded by NSF that allows students to contribute to the development of novel biomimetic microelectronic systems based on fundamental principles of biology in one of three testbeds: retinal prosthesis, neuromuscular prosthesis, and cortical prosthesis. BMES ERC invites talented undergraduates to participate in active research projects and work alongside world-renowned researchers and students.

Credit: University of Southern California, BMES ERC

5. Mixing of Fluorescent Dye in Stirred Tank Reactor

A fluorescent dye injected into a tank of stirred liquid creates a pattern that resembles a green apple. The demonstration, conducted by Rutgers University researchers from the NSF Engineering Research Center on Structured Organic Composites (C-SOC) shows how liquids mix in a typical pharmaceutical manufacturing operation. Engineers will use such studies to help drug makers improve product uniformity. In this view, a four-blade impeller attached at the bottom of the vertical shaft, visible at the center of the image, draws fluid from above and creates outgoing ripples in the flow. Dye injected from above is rapidly advected around a toroidal shell, but penetrates slowly into the interior: this separation between the outside and the inside of mixing regions represents a bottleneck to processing and a challenge to the generation of reproducible product uniformity. The NSF Engineering Research Centers (ERC) program established C-SOC to study the nature of finely ground granular materials and other substances that form the core of drug tablets, processed foods, agricultural chemicals, and other "composite organic" products. In addition to improving the quality and consistency of such materials, the center will develop more consistent and cost-effective manufacturing techniques than methods based largely on trial and error.

Credit: M. M. Alvarez, T. Shinbrot, F. J. Muzzio, Rutgers University, Center for Structured Organic Composites

6. "Torus II"

This image, from the Eric J. Heller Gallery, is a three-dimensional image (plotted in two dimensions) of a four-dimensional object. When classical motion of particles is not chaotic, it is integrable; it can be confined to the surface of donut-shaped objects or "tori," which live in four or more dimensions. The torus appears to intersect itself, because the viewer pretends it exists in three dimensions. In the four-dimension space, it does not intersect. The surface of the torus was made partially transparent to reveal the structure within. Heller's work was included in the exhibit "Approaching Chaos," shown at NSF, as part of "The Art of Science Project."

Credit: Eric J. Heller, Harvard University

7. Robotics Competition

Students from "McKinley Robotics - Team Kika Mana" at President William McKinley High School in Honolulu, Hawaii. Pictured from left to right are: Iat Ieong (co-captain), Jinny Park (co-captain), Calvin Ing, and James Park. The robot is "Hot Lava," and was part of the 2007 Robotics Competition called "Rack 'n Roll."

Credit: National Science Board Office

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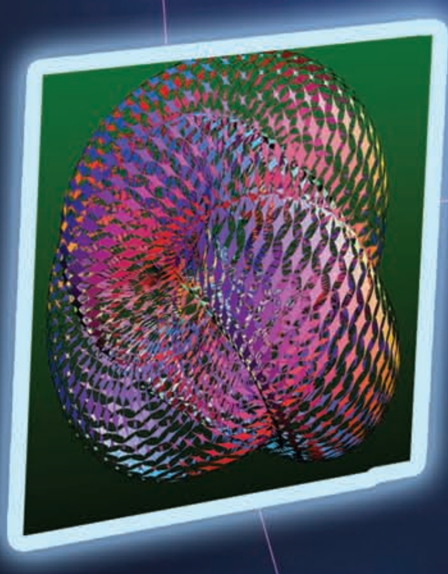
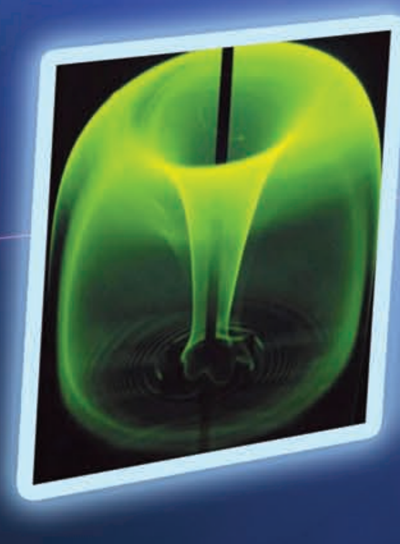

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