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.

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[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

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| 9:30 a.m. | **Panel 2: Engineering Education – Present and Future** | |
| | Moderator: Daniel Hastings, National Science Board | |
| | Alice Agogino*<br>University of California, Berkeley | Eli Fromm*<br>Drexel University |
| | Richard Miller*<br>Olin College of Engineering | Tom Magnanti*<br>MIT |
| | Linda Katehi*<br>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**<br>***By Invitation Only*** | |
| | Susan Hockfield*, President, MIT | |
| | John H. Marburger, III*, Science Advisor to the President<br>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*<br>Raytheon Company | Jim Miller*<br>Cisco Systems, Inc. |
| | Ron Hira*<br>IEEE-USA | Gloria Jeff*<br>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) |

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| 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<br>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 |

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| 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