APPENDIX A

5XME Workshop White Paper

THE “5XME” WORKSHOP: TRANSFORMING MECHANICAL ENGINEERING EDUCATION AND RESEARCH IN THE USA

M.L. Good, M. Jones, L. Matsch, C.D. Mote, Jr. and A.G. Ulsoy

The launch of the first artificial satellite, Sputnik, by the USSR in 1957 precipitated a transformative change in engineering education in the USA, towards a science-based engineering curriculum focused on fundamentals. For example, mechanical engineering education emphasized thermodynamics, heat transfer, fluid mechanics, solid mechanics and dynamics. Topics from mechanical engineering practice, such as internal combustion engines, heat exchangers, automotive body structures and machine tools, became viewed as applications of those fundamentals. This emphasis on fundamentals empowered engineering students, and enabled graduates to apply their knowledge and skills in a variety of different industries, and in emerging new technologies (e.g., aerospace, nuclear, computer, biomedical). However, this same emphasis on fundamentals has led to a weak link to engineering practice, and a lack of emphasis on industrial innovation and commercialization of technology.

Globalization, with the open flow of information, goods and people all over the world, brings significant benefits to all. However, it also creates challenges for the nation. In engineering education many countries now emulate the very successful USA engineering schools and their science-based curricula, and are making investments that produce an order of magnitude more engineers, and of comparable quality. Global companies employ such world-class engineering talent, often at 20% of the cost in the USA, and are moving manufacturing, design and even research activities to such locations. Furthermore, the national investment in mechanical engineering research, which has fueled the economy for decades with breakthrough technologies (e.g., CAD systems, MRI machines, non-destructive evaluation methods), is also being emulated by other nations around the world, which are recognizing the importance of engineering for economic prosperity, and are making the societal investments in engineering research and education. However, given current societal values, the USA is unlikely to significantly increase taxes for further public support of engineering education and research; in fact such public support has been eroding over the past 50 years.

We now face a national crisis more dramatic than the launching of Sputnik in 1957, and one that will require a creative and transformative response in terms of engineering education. The economy and prosperity of the nation will depend on our ability to respond effectively to such a changing environment, especially in core engineering disciplines like mechanical engineering. Mechanical engineering, which is often viewed as a mature discipline, is in fact rapidly evolving to encompass emerging areas such as mechatronics, MEMS, biotechnology, medical devices, cognitive engineering and nanotechnology. Furthermore, it retains a strong focus on design and manufacturing and remains one of the largest engineering disciplines in terms of undergraduate degrees and enrollments. *The challenge for engineering schools in the USA is how to educate a mechanical engineer that provides five times the value added when compared to the global competition, i.e., the “5XME”.*

Mechanical engineering education and research in the USA will need to link more closely with engineering practice and the commercial world to generate the necessary market pull and resources for such a transformation. However, the current emphasis on engineering fundamentals cannot be sacrificed. To achieve the "5XME," mechanical engineering education must be transformed to embrace both fundamentals and practice; both the procedural knowledge of the problem-solving engineer as well as the declarative knowledge of the applied scientist. A similar transformation occurred in the automotive industry when some companies realized that they could beat the competition by producing vehicles that were *both* high in quality and low in cost. Also analogous is the transformation in medicine that occurred with the Flexner report in 1910, which led to a medical education based upon both scientific and clinical training.

The transformation needed in mechanical engineering education must embrace societal priorities, and become an exciting and attractive leadership opportunity for a diverse pool of talent from all segments of our society. Such a transformation will require a new infrastructure, and new methods of educational delivery, that develop the specific abilities of diverse students, to achieve the attributes that graduates must possess, e.g.:

1. Broad grounding in fundamentals
2. Flexibility and agility
3. Innovation and creativity to benefit society
4. Global focus
5. Teamwork and leadership
6. Communication skills

In education: Engineers must be broadly educated, not simply to solve problems others have set for them, but to identify problems and issues and to provide the technological leadership needed to benefit society. We must fully develop the potential and all the skills of our students to develop the new renaissance engineer, and bring the successful research and project focus of graduate education to undergraduate students in engineering.

In research: Engineers must practice concurrent discovery and innovation to fuel the economy, and benefit society, in a time of accelerating technological change. Emerging areas, such as macro systems (e.g., innovation, energy, environment, enterprises, service industries, health care, complex systems), micro/nano systems, bioengineering, information technology and cognitive engineering present new opportunities.

Similar to the change that occurred in engineering, to become a science-based discipline, after the launch of Sputnik in 1957, we are now looking for another transformative change to engineering education; this time in response to the global competition, and specifically to the fact that a science-based engineering education has become a commodity available to students all across the world, including low-wage markets. We urgently need to identify the attributes that the mechanical engineering graduate in the USA must posses to compete successfully in a global marketplace, where global companies hire engineering talent and establish engineering services, anywhere in the world. We need to identify the mechanisms (e.g., courses, curricula, internships, projects, engineering clinics) by which those students will acquire such attributes. We also need to develop a strategy, tactics and resources to move ahead with such a transformation on a national scale.

The National Science Foundation is sponsoring a workshop, to be held during May 10-11, 2007, to discuss these important and urgent issues, and to initiate the process of transformation (see http://www.umich.edu/~ulsoy/5XME.htm).

Selected References

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APPENDIX B

5XME Workshop Agenda

THE "5XME" WORKSHOP:
TRANSFORMING MECHANICAL ENGINEERING EDUCATION AND RESEARCH IN THE USA

May 10-11, 2007
National Science Foundation, 4201 Wilson Blvd, Arlington, VA
Stafford-II, Room 555 (and Rooms 525, 595)

AGENDA

Thursday May 10

8:00 *Registration and continental breakfast*

8:15 Welcome and self-introductions

8:30 Opening Remarks

- Arden L. Bement , Director, National Science Foundation
- Richard O. Buckius , Assistant Director, Engineering Directorate, NSF

9:00 Plenary session I

- *Summary of 5XME workshop white paper*, A. Galip Ulsoy, W.C. Ford Professor of Manufacturing, University of Michigan
- *Reinventing ME workshop and renaissance engineer*, Adnan Akay, Director, Division of Civil, Mechanical and Manufacturing Innovation, NSF
- *Summary of NRC report on benchmarking US research competitiveness in mechanical engineering*, Ward O. Winer, E.C. Gwaltney, Jr. Chair of the Woodruff School of Mechanical Engineering and Regent's Professor, Georgia Institute of Technology

10:15 *Coffee Break*

10:30 Plenary session II

- *Globalization and Engineering Education*, Nariman Farvardin, Dean and Professor of Electrical and Computer Engineering, University of Maryland.
- *Reinventing Engineering for the 21st Century*, James J. Duderstadt, President Emeritus and University Professor of Science and Engineering, University of Michigan

12:30 *Lunch Break – on your own.*

2:00 3-Breakout sessions Groups A1, A2, A3

3:00 Report back

3:15 *Coffee Break*

3:45 3 Breakout sessions Groups B1, B2, B3

4:45 Report back

5:00 Adjourn

6:30 *Reception and Dinner (DaVinci Suite, Arlington Hilton)*

Friday May 11

8:00 *Continental breakfast*

8:30 3 Breakout sessions Groups C1, C2, C3

10:00 Report back

10:30 *Coffee Break*

11:00 Discussion of recommendations

12:00 *Lunch Break – on your own.*

1:30 Outline of report, next steps, and assignment of tasks

3:00 Adjourn

Proposed Breakout Groups[1]:

1. Earl Dowell (moderator), Richard Taber (recorder), Al Pisano, Mario Rotea, Sheri Sheppard, Pat Moran, Nariman Farvardin, Eduardo Misawa, Allan Soyster, Richard Buckius.
2. Bill Wepfer (moderator), Gretar Tryggvasson (recorder), Bill Miller, Fritz Prinz, Marshall Jones, Robert Clark, Galip Ulsoy, Jim Duderstadt, , Judy Vance.
3. Pam Eibeck (moderator), Deba Dutta (recorder), Andrew Alleyne, Bob Warrington, Norm Fortenberry, Rohan Abeyaratne, Ward Winer, Tom Perry, Adnan Akay, Arden Bement.

Possible Breakout Topics, e.g.,

Group A – focused on needs/opportunities, e.g.

- Necessary attributes of the 5XME (e.g., fundamentals, agility, innovation, global focus, leadership, communication)?
- Emerging areas (bio, nano/micro, cogno, macro, eco/energy, ..)?
- Attracting students to engineering from all societal groups?

Group B – focused on possible initiatives, e.g.

- Teaching procedural knowledge (e.g., engineering problem-solving, design, research, innovation)?
- Project/research based UG education (e.g., Boyer commission report)?
- Concurrent discovery and innovation in graduate education?

Group C – focused on recommendations, e.g.

- Engineering clinics, discovery/innovation institutes?
- Renaissance engineers: developing the individual?
- Engineering liberal arts bachelors, professional masters?

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[1] I have taken the liberty to assign people to breakout groups, and to assign a moderator and recorder for each group. Please let me know if you would like to change these by contacting ulsoy@umich.edu.

APPENDIX C

5XME Participants List

WORKSHOP PARTICIPANTS

1. Adnan Akay, NSF, aakay@nsf.gov
2. Al Pisano, UCB, appisano@me.berkeley.edu
3. Allen L. Soyster, NSF, asoyster@nsf.gov
4. Andrew Alleyne, UIUC, alleyne@uiuc.edu
5. Arden Bement, NSF, abement@nsf.gov
6. Bill Miller, ETAS, bill.miller@etas.us
7. Bill Wepfer, GaTech, bill.wepfer@glc.gatech.edu
8. Bob Warrington, MTU, row@mtu.edu
9. Deba Dutta, U. Mich., dutta@umich.edu
10. Earl Dowell, Duke dowell@ee.duke.edu
11. Eduardo Misawa, NSF, emisawa@nsf.gov
12. Fritz Prinz, Stanford, mechair@me.stanford.edu
13. Galip Ulsoy, U. Mich., ulsoy@umich.edu
14. Gretar Tryggvasson. WPI, gretar@wpi.edu
15. Jim Duderstadt, U. Mich., jjd@umich.edu
16. Judy Vance, NSF, jmvance@nsf.gov
17. Mario Rotea, U Mass, rotea@ecs.umass.edu
18. Marshall Jones, GE, jonesmg@crd.ge.com
19. Nariman Farvardin, UMD farvar@eng.umd.edu
20. Norman Fortenberry, NAE nfortenb@nae.edu
21. Pam Eibeck, Texas Tech, Pamela.eibeck@ttu.edu
22. Richard Buckius, NSF, rbuckius@nsf.gov
23. Robert L. Clark, Duke, rclark@egr.duke.edu
24. Rohan Abeyaratne, MIT, rohan@mit.edu
25. Sheri Sheppard, Stanford, Sheppard@cdr.stanford.edu
26. Tom Perry, ASME, PerryT@asme.org
27. Ward Winer, Ga. Tech., ward.winer@me.gatech.edu

APPENDIX D

5XME Workshop Plenary Presentations

- *Welcoming Remarks,* Arden L. Bement , Director, National Science Foundation
- *Opening Remarks,* Assistant Director, Engineering Directorate, NSF
- *Summary of 5XME workshop white paper,* A. Galip Ulsoy, W.C. Ford Professor of Manufacturing, University of Michigan
- *The need for a Renaissance in Engineering Education- BS to PhD,* Adnan Akay, Director, Division of Civil, Mechanical and Manufacturing Innovation, NSF
- *NRC panel on benchmarking US research competitiveness in mechanical engineering*, Ward O. Winer, E.C. Gwaltney, Jr. Chair of the Woodruff School of Mechanical Engineering and Regent's Professor, Georgia Institute of Technology
- *Globalization and engineering education*, Nariman Farvardin, Dean and Professor of Electrical and Computer Engineering, University of Maryland.
- *Introduction to 21st century engineering*, James J. Duderstadt, President Emeritus and University Professor of Science and Engineering, University of Michigan
- *A roadmap to 21st century engineering,* James J. Duderstadt, President Emeritus and University Professor of Science and Engineering, University of Michigan

Dr. Arden L. Bement, Jr.
Director
National Science Foundation

Welcoming Remarks
The 5XME Workshop:
Reforming Mechanical Engineering Education and Research in the U.S.
May 10, 2007

Good morning to everyone, and welcome to the National Science Foundation. I'm always delighted to talk at Workshops because groups like you play such an important role in helping NSF identify new frontiers. So thank you for undertaking this important work.

And there's no doubt about it. Preparing the nation's engineers to be leaders in the 21st Century is vital to the nation's future. And that is true for all fields of engineering, mechanical as well as others.

We can all agree that there is no longer any merit for U.S. industry to aspire to be the low-cost producer of commodity products. We started outsourcing such production to developing countries decades ago and that outsourcing continues. Today, many worry that such competition is moving rapidly up the value chain to encompass high-end innovation. And the same is true for the R&D engineers who are driving innovation.

The challenge for engineering schools in the U.S. is to educate engineers who can provide 5 times the added value to U.S. production. That's the thesis driving this workshop and the source of the "5X" in 5XME.

For some time now, articles and reports have stressed the need to reform engineering education to meet the new challenges of the emerging global innovation system. And there are some shining examples of university programs that embody exciting new models of engineering education.

But all too often, inertia seems to be the ruling force in today's engineering schools. We will need perseverance to confront the "stickiness" of that traditional culture in order to generate meaningful change.

Certainly other nations are acting with determination to realize their own vision of the future, including how to educate the engineers who are central to their own technology-driven societies.

Although Tom Friedman claims that "the world is flat", in reality it is highly "spiked." When it comes to the global distribution of S&E talent and world-class research infrastructure, the U.S. still represents one of the largest spikes. Indeed, it's no exaggeration to say that U.S. universities maintain world leadership in science and engineering education.

But that is changing rapidly. We can't afford to be complacent today if we want to educate engineers who will be leaders tomorrow.

This brings me back to producing "5X" engineers. There are several dimensions in which engineering education can be shaped to add this value. Let me briefly outline several.

The Collaboration Dimension

Today's engineering involves more interdisciplinary work, greater collaboration, and a trend toward international participation in research projects.

In the private sector, even start-up companies may be "international" from the outset. In addition to technical knowledge and skills, engineers need well-honed "collaborative competencies" that include the ability to cooperate and communicate across disciplines, distances, and cultures.

More than most, engineers need these skills to become valuable leaders in the new global innovation system.

The Social Dimension

Many women and underrepresented minorities are strongly motivated by social and community involvement.

They want to be assured that engineers are socially relevant and help people improve the quality of their lives.

The EPICS program (Engineering Projects in Community Service), which the NSF supports, is one of the best examples I know of a program that demonstrates the relevance of engineers to social goals.

The Research Dimension

One of the time-tested precepts at NSF is that integrating research with education is a powerful way to motivate and retain students, and at the same time prepare world-class scientists and engineers for the workplace.

NSF's REU program (Research Experience for Undergraduates) is proving to be a potent means to retain undergraduates to first degree and also attract them to graduate study.

The REU program is also a channel for steering women and underrepresented minorities into graduate education. Students in REU programs are now highly diverse in ethnicity and gender.

The Information Technology Dimension

As we move from terascale to petascale computing, we will be able to simulate and model engineering systems of unprecedented levels of complexity. For example, it will soon be possible to model the entire U.S. electric power grid, with all of its chaotic and emergent behavior.

To realize these prospects, however, will require not only computer and software engineers, but also engineers who can team with the problem solvers and modelers to develop the best cyberinfrastructure to achieve optimal computation performance. As yet, there are relatively few universities educating these "computational engineers."

In fact, engineers who are "cyber savvy" to a high degree will have an enormous leg up in becoming engineering leaders. In the next decade, excellence in cyberinfrastructure may well determine which nation sets the pace in global education excellence. NSF has made the development of shared, broadly accessible cyberinfrastructure a top priority across all disciplines.

The Systems Dimension

Engineers also need to be prepared to design in the context of higher-order complexity in business processes and models.

This context includes the growing disaggregation of vertical "supply" chains, from raw materials to finished assemblies, and also horizontal "support" chains that provide services across the operational spectrum from initial design to accounts payable.

They must also be aware of emerging multi-sectoral enterprise integration and the role information technology will surely play in making these new integrated business systems function efficiently. For example, it will not be possible to enter the hydrogen economy without interlocking partnerships among the energy, transportation, manufacturing, and financial sectors.

The Innovation Dimension

When it comes to bringing new technologies into the market place, engineers are generally on the front line. Global success in market competition increasingly depends on destabilizing established markets with "killer" products and applications, ……and doing so with ever decreasing lead times.

To be successful, engineers will need to be skilled in anticipating change. They will also need to understand not only the technological dimensions but also the business, marketing, and financial dimensions of the innovation system.

Ever shortening lead times will not afford high technology companies the luxury of fostering separate engineering, business, marketing, and sales cultures. Therefore, engineers will have to be able to communicate effectively in "jargon-free" speech across the entire enterprise spectrum.

The Human Dimension

Corporations have learned that they ignore customer attitudes at their own peril. If we genuinely want to prepare today's students to be world-class engineers, we should consider the possibility that we need to reform education to better suit the attitudes and experience they bring with them to university.

Anyone who has spoken to a teenager recently knows all too well that these young people are coming from a different place than we did 20 to 50 years ago! We need to understand exactly what youngsters today bring to the table—and do a better job serving them a wholesome meal.

A benefit of thinking about kids as customers with a world view of their own might be that more of today's youngsters will find the prospect of becoming an engineer more appealing.

Crafting engineering education programs that can address these many dimensions is certainly a daunting challenge. It is a challenge that cannot be met using standard methods of pedagogy.

We will need to experiment with a variety of platforms and methods, maintaining the flexibility to make course corrections along the way. A narrow focus at this stage is risky, because betting on a single path could delay our progress.

I hope that this workshop will provide new insights on how we should proceed along these new paths. The NRC Report "Educating the Engineer of 2020" provides a solid framework to build on.

The NSF is eager to receive your workshop proceedings and to work with the broad community of engineering educators to provide the engineering workforce the nation will need for the 21st Century.

5XME Workshop: Transforming ME Education and Research in the USA

May 10-11, 2007
Arlington, VA

National Science Foundation
Directorate for Engineering

Assistant Director for Engineering
Richard O. Buckius

Public Perceptions

Washington Post Op-Ed, May 6, 2007

- "…Because U.S. labor cannot compete on price, we must reemphasize the things that have kept us on top of the economic food chain for so long: technology, innovation, entrepreneurship, adaptability and the like. That means more science and engineering, more spending on R&D ..."

  "… we need to rethink our education system so that it turns out more people who are trained for jobs that will remain in the US …"

  Alan S. Blinder, Economics, Princeton University

- We need to stay one step ahead.

NSF Investment Timeline

1980
- President eliminates education programs at NSF

1985
- National Science Board Homer Neal Report
- Presidential Young Investigators
- Engineering Research Centers
- Calculus Reform
- Instructional Labs
- Research Experience for Undergraduates

1990
- Coalitions
- ABET
- Graduate Engineering Fellowships & Traineeships
- Course & Curriculum Development
- Instrumentation & Laboratory Improvement
- UG Faculty Enhancement

1995
- Model Institutions for Excellence
- ADVANCE
- Louis Stokes Alliances for Minority Participation
- Alliances for Graduate Education and the Professoriate
- Advanced Technological Education

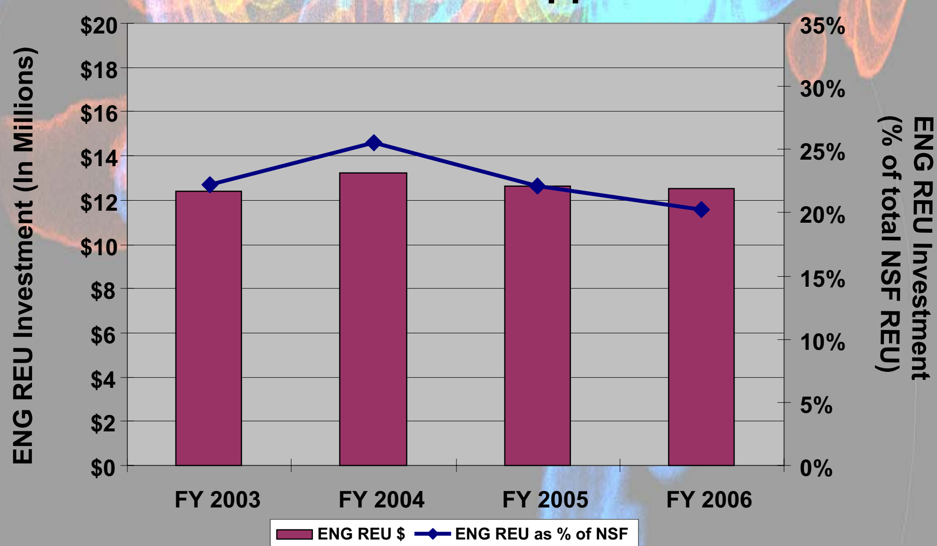
2000
- NAE Center for Advancement of Scholarship in Engineering Education
- Science, Technology, Engineering & Mathematics Talent Expansion Program
- Department Level Reform
- Research Experience for Teachers
- Centers for Teaching and Learning

2005
- American Competitiveness Initiative
- NA Rising Above the Gathering Storm
- NAE Engineer of 2020 and Educating the Engineer of 2020
- Engineering Education Departments
- Research Agenda for Engineering Education

Research Experiences for Undergraduates

REU Background

- To encourage U.S. citizens to pursue doctoral studies by engaging them in research as undergraduates
- Includes both REU sites and supplements



Research Experiences for Undergraduates

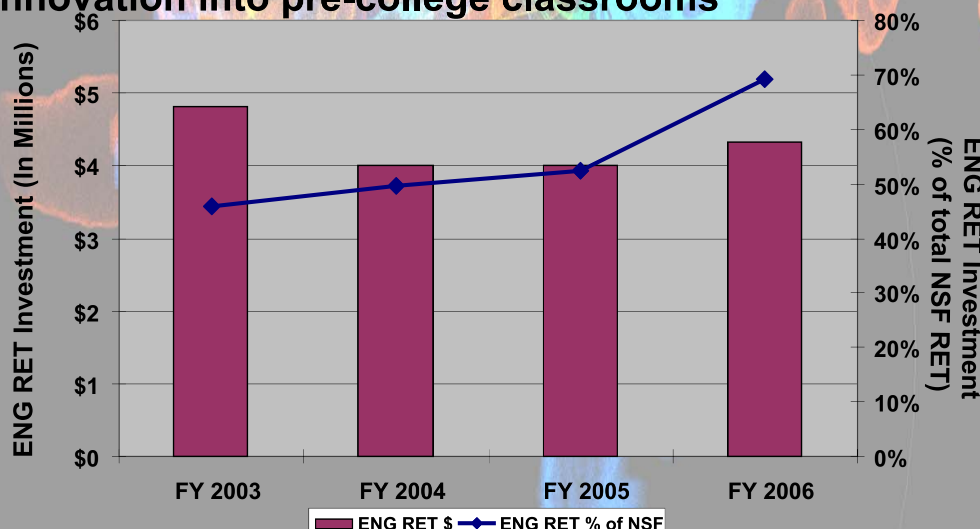
Findings

- ➔ SRI evaluated the NSF-wide program in 2006
  - Included almost 15,000 respondents
  - Engineering-specific results were not obtained
  - In general, there is significantly higher graduate school attendance, increased understanding of research processes, and increased awareness and interest of academic and research careers
  - For example,
    - 6 in 10 participants indicated that REUs were important in their decision to apply to graduate school
    - Half to two-thirds of the respondents reported that their REUs increased their interest in STEM careers and research
  - Recommendations include REUs and inquiry-based activities earlier in student's programs

Research Experiences for Teachers

RET Background

- ➔ Supports the active involvement of K-12 teachers and community college faculty in engineering research
- ➔ Brings knowledge of engineering and technological innovation into pre-college classrooms



Research Experiences for Teachers

Findings

- SRI completed an assessment of RET in selected fields of engineering in 2006 finding:
  - Teachers add engineering content and process to their pre-college courses. 94 percent of teachers reported increased motivation to find ways to improve student learning, and 89 percent of teachers reported increased confidence in teaching science and math.
  - Teachers report dramatic increase in understanding of engineering. They are much better prepared to counsel students to pursue engineering.
  - Need to provide continuing opportunities for teachers and faculty interactions.

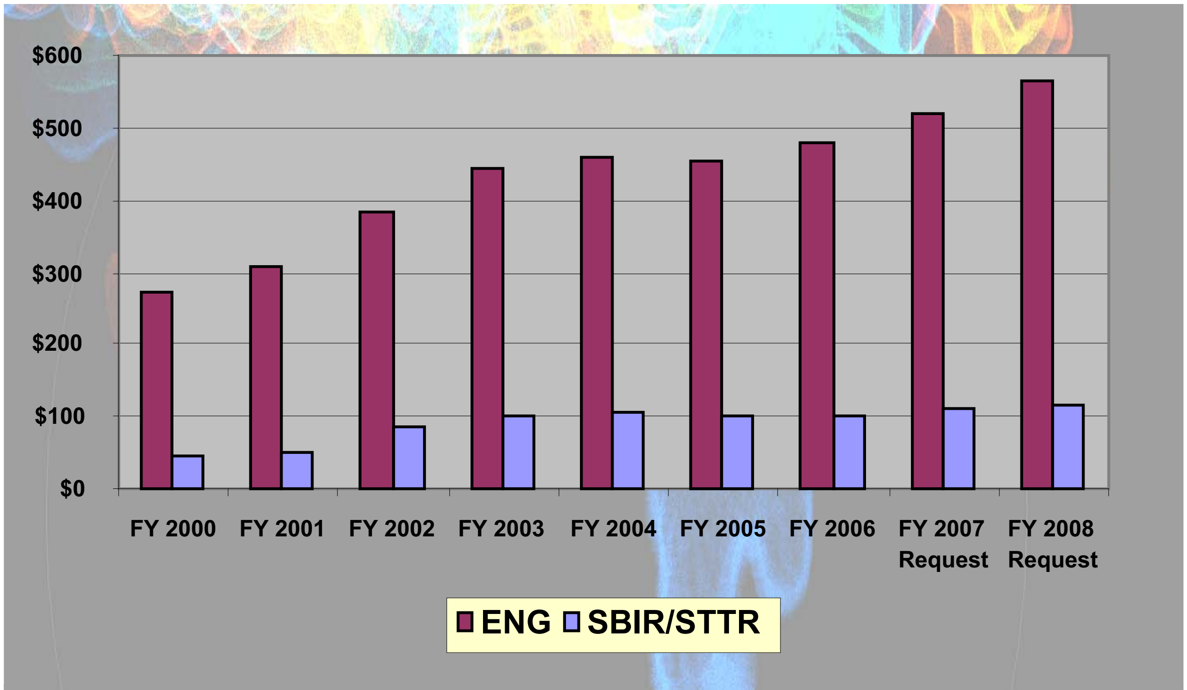
ENG Education and Workforce

- ENG directly and indirectly invests in workforce activities

ENG Major Investments	FY 2005	FY 2006
RET – sites and supplements	$4.00 million	$4.33 million
REU – sites and supplements	$12.62 million	$12.52 million
Engineering Education	$13.26 million	$14.63 million
NSF-wide activities	$24.28 million	$24.43 million
ERC education activities	$11.80 million	$11.90 million
CAREER	$37.27 million	$39.36 million
BBSI/NNCS/NUE	$3.25 million	$3.20 million
SBIR/STTR Programs	$0.60 million	$1.20 million
ENG Grad Research Diversity Sups	$0.6 million	$1.20 million
Tribal Colleges	NA	$0.25 million

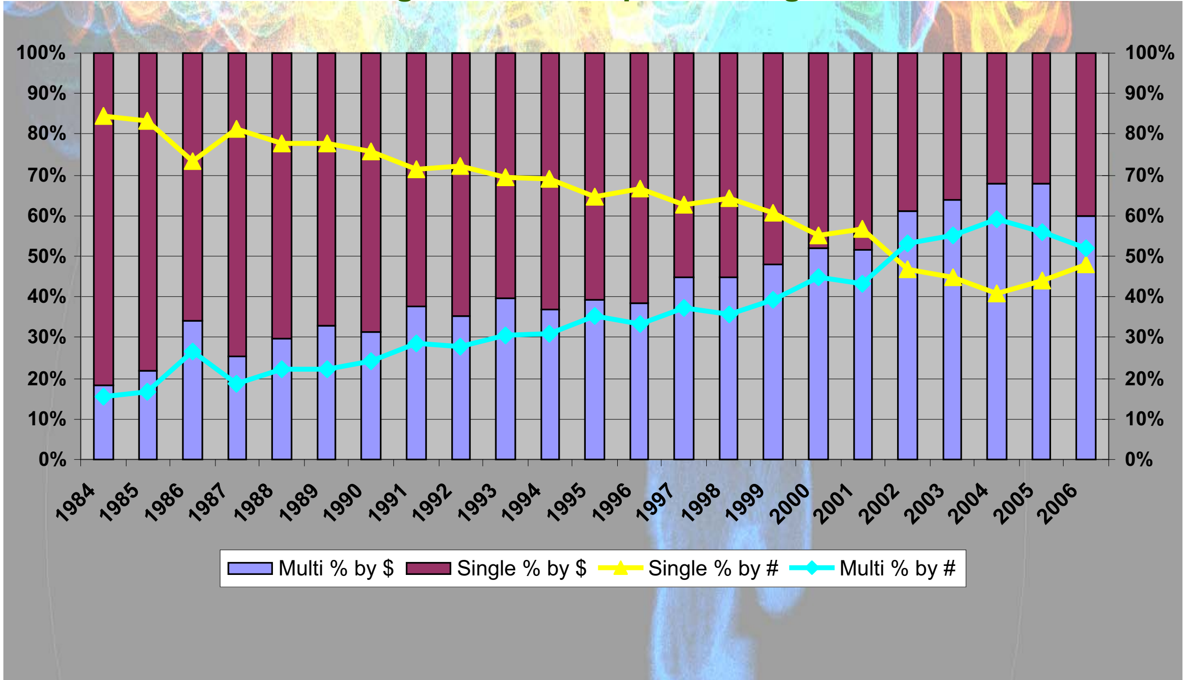
ENG and SBIR/STTR Budgets

Dollars in Millions



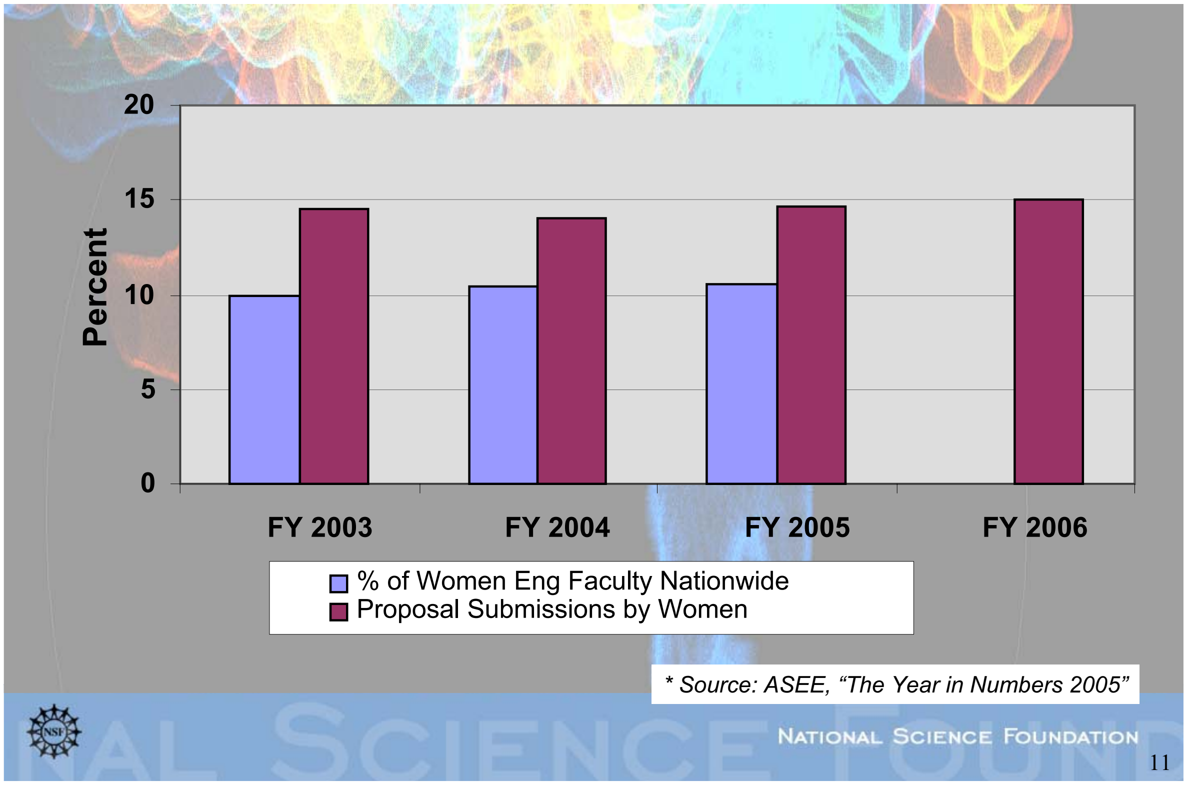
Research Collaborations

Percent of Single PI vs. Multiple Investigator Awards



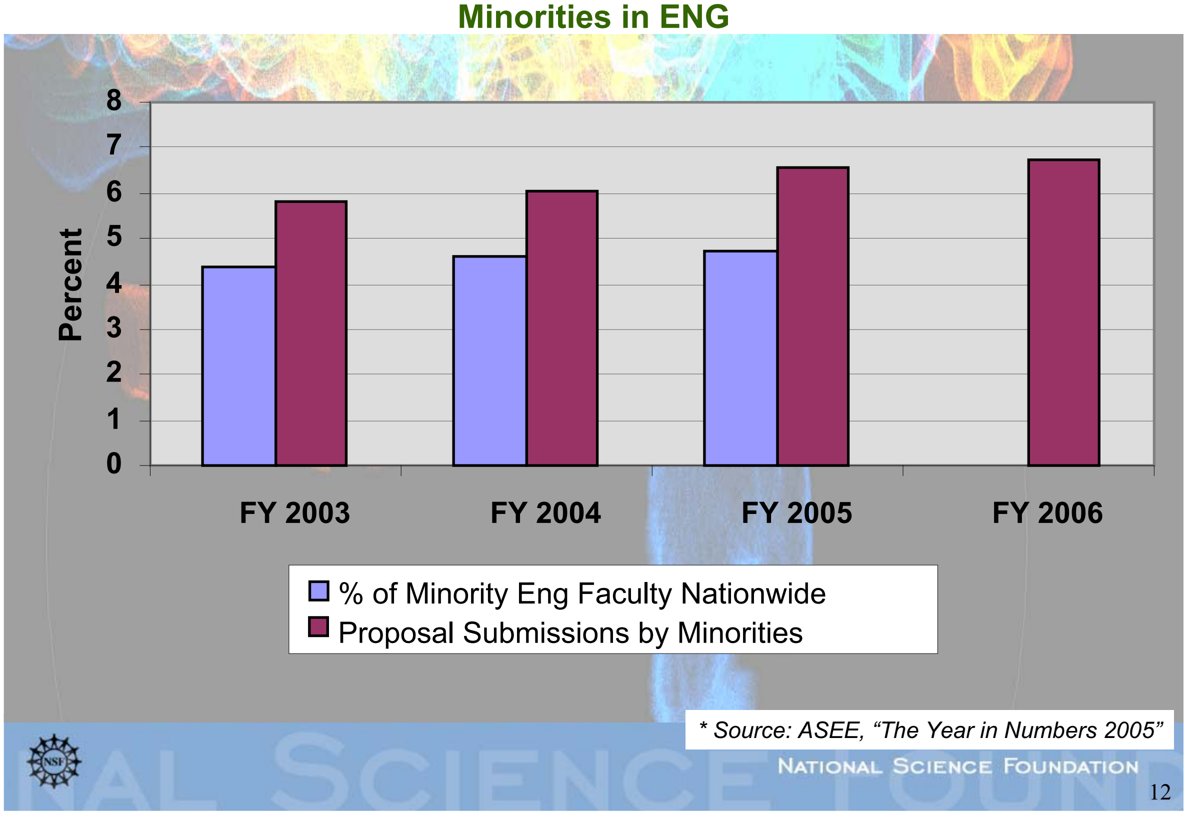
Research Proposal Submissions

Women in ENG



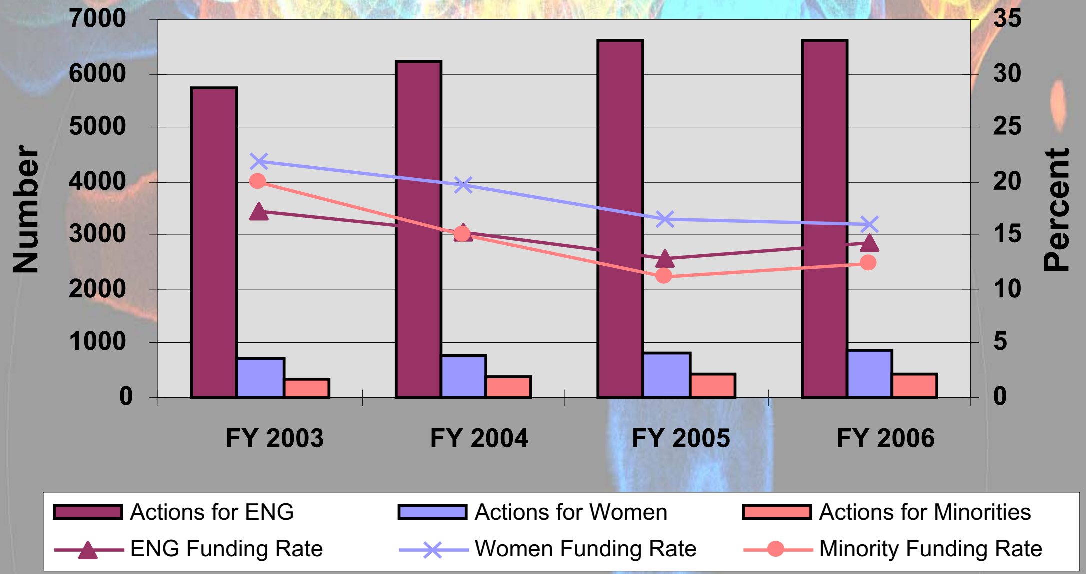
Research Proposal Submissions

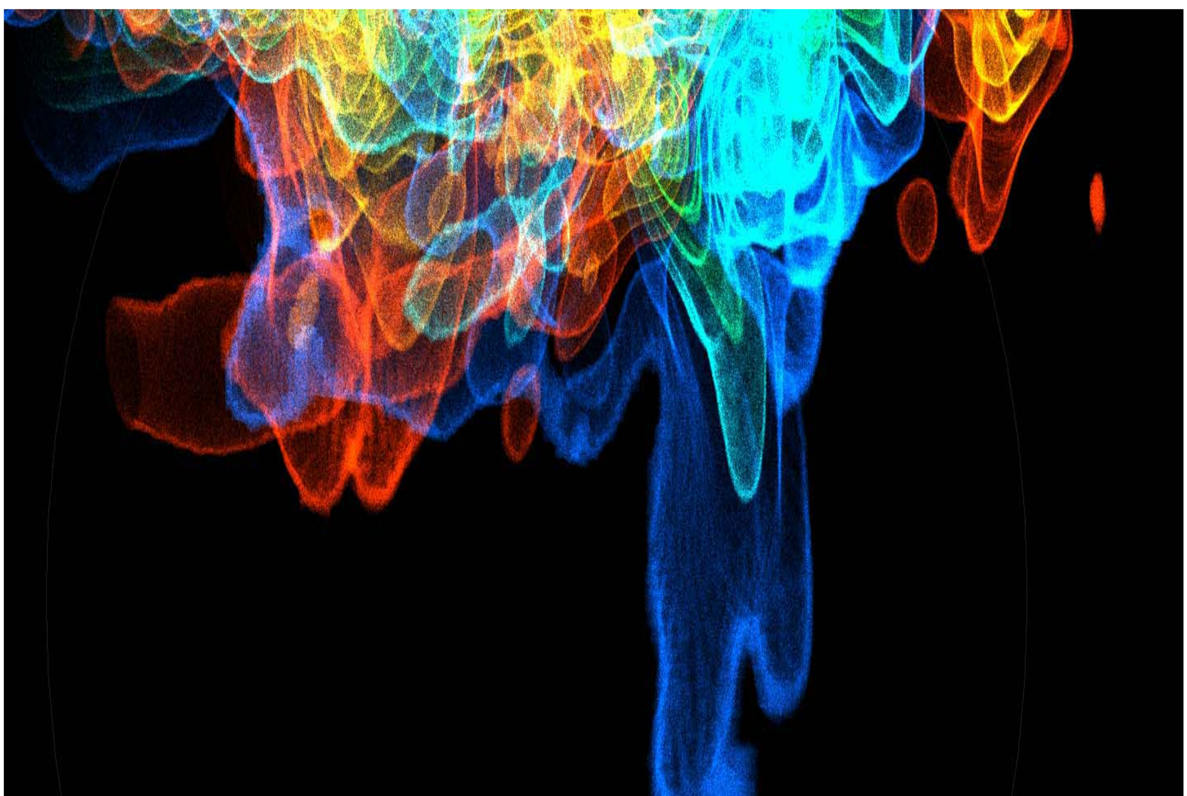
Minorities in ENG



Funding Rates

Research Proposals among All ENG, Women, and Minorities





THE "5XME" WORKSHOP:

TRANSFORMING MECHANICAL ENGINEERING EDUCATION AND RESEARCH IN THE USA

May 10-11, 2007
Arlington, VA

Workshop Goal

- To lay the foundation for *transformative* change in mechanical engineering education and research in the USA.
- The science-based engineering education taught at our engineering schools has become a commodity, available to students all over the world, including low-wage markets. Global companies employ such world-class engineering talent, often at 20% of the cost in the USA, and are moving manufacturing, design and even research activities to such locations.
- *The challenge for engineering schools in the USA is how to educate a mechanical engineer that provides five times the value added when compared to the global competition, i.e., the "5XME."*

Background

- A workshop planning committee, consisting of Mary Good, Marshall Jones, Lee Matsch, Dan Mote and Galip Ulsoy met during July 2006 at NSF to discuss this issue and proposed this workshop. Observers from NSF included Adnan Akay, Richard Buckius, and others.
- This planning committee also drafted the "White Paper" that you have in your packet of materials, and which contains some preliminary statements of needs and possible actions.

Excerpts from White Paper

- **To achieve the "5XME," mechanical engineering education must be transformed to embrace both fundamentals and practice; both the procedural knowledge of the problem-solving engineer as well as the declarative knowledge of the applied scientist.**
- **The transformation must embrace societal priorities, and become an exciting and attractive leadership opportunity for a diverse pool of talent from all segments of our society. Such a transformation will require a new infrastructure, and new methods of educational delivery, that develop the specific abilities of diverse students, to achieve the attributes that graduates must possess, e.g.:**
  - Broad grounding in fundamentals
  - Flexibility and agility
  - Innovation and creativity to benefit society
  - Global focus
  - Teamwork and leadership
  - Communication skills

Excerpts from White Paper

- Engineers must be broadly educated, not simply to solve problems others have set for them, but to identify problems and issues and to provide the technological leadership needed to benefit society. We must fully develop the potential and all the skills of our students to develop the new renaissance engineer, and bring the successful research and project focus of graduate education to undergraduate students in engineering
- Engineers must practice concurrent discovery and innovation to fuel the economy, and benefit society, in a time of accelerating technological change. Emerging areas, such as macro systems (e.g., innovation, energy, environment, enterprises, service, health care, complex systems), micro/nano systems, bioengineering, information technology and cognitive engineering present new opportunities.

Excerpts from White Paper

- Similar to the change that occurred in engineering, to become a science-based discipline, after the launch of Sputnik in 1957, we are now looking for another transformative change to engineering education; this time in response to the global economic competition, and specifically to the fact that a science-based engineering education has become a commodity available to students all across the world, including low-wage markets.
- We urgently need to identify the attributes that the mechanical engineering graduate in the USA must posses to compete successfully in a global marketplace, where global companies hire engineering talent and establish engineering services, anywhere in the world.
- We need to identify the mechanisms (e.g., courses, curricula, internships, projects, engineering clinics) by which those students will acquire such attributes.
- We also need to develop a strategy, tactics and resources to move ahead with such a transformation on a national scale.

Workshop Program

- **Plenary speakers to present some ideas and issues and to get our thinking focused on the workshop goal**
- **Breakout sessions to share, discuss and debate potential ideas for the "5XME" transformation**
- **Develop an outline of the report to capture key ideas and recommendation of workshop participants**
- **Finalize report after the workshop, and disseminate for discussion and action in the broader mechanical engineering community.**

Possible Outcomes and Future Steps

- **Present Workshop Ideas to Broader Mechanical Engineering Audience:**
  - Workshop Report, Brochure and Web Site
  - Symposium at the ASME Mechanical Engineering Education Conference (MEEC) in 2008.
- **Potential opportunities via NSF to pilot transformative educational initiatives.**
- **Other?**

AGENDA (Thu AM)

- **9:00 Plenary session I**
  - A. Galip Ulsoy, W.C. Ford Professor of Manufacturing, University of Michigan
  - Adnan Akay, Director, Division of Civil, Mechanical and Manufacturing Innovation, NSF
  - Ward O. Winer, E.C. Gwaltney, Jr. Chair of the Woodruff School of Mechanical Engineering and Regent's Professor, Georgia Institute of Technology
- **10:15 *Coffee Break***
- **10:30 Plenary session II**
  - Nariman Farvardin, Dean and Professor of Electrical and Computer Engineering, University of Maryland.
  - James J. Duderstadt, President Emeritus and University Professor of Science and Engineering, University of Michigan

AGENDA (Thu PM)

- 12:30 *Lunch Break – on your own.*
- 2:00 3-Breakout sessions Groups A1, A2, A3
- 3:00 Report back
- 3:15 *Coffee Break*
- 3:453 Breakout sessions Groups B1, B2, B3
- 4:45 Report back
- 5:00 *Adjourn*
- 6:30 *Reception and Dinner*

  (DaVinci Suite, Arlington Hilton)

AGENDA (Fri)

- 8:00 *Continental breakfast*
- 8:30 3 Breakout sessions Groups C1, C2, C3
- 10:00 Report back
- 10:30 *Coffee Break*
- 11:00 Discussion of recommendations
- 12:00 *Lunch Break – on your own.*
- 1:30 Outline of report, next steps, and assignment of tasks
- 3:00 *Adjourn*

BREAKOUT TOPICS

A – focused on needs/opportunities, e.g.

- Necessary attributes of the 5XME (e.g., fundamentals, agility, innovation, global focus, leadership, communication)?
- Emerging areas (bio, nano/micro, cogno, macro, eco/energy, ..)?
- Attracting students to engineering from all societal groups?

B – focused on possible initiatives, e.g.

- Teaching procedural knowledge (e.g., engineering problem-solving, design, research, innovation)?
- Project/research based UG education (e.g., Boyer report)?
- Concurrent discovery and innovation in graduate education?

C – focused on recommendations, e.g.

- Engineering clinics, discovery/innovation institutes?
- Renaissance engineers: developing the individual?
- Engineering liberal arts bachelors, professional masters?

BREAKOUT GROUPS

1. **Earl Dowell (moderator), Richard Taber (recorder), Al Pisano, Mario Rotea, Sheri Sheppard, Pat Moran, Nariman Farvardin**

2. **Bill Wepfer (moderator), Gretar Tryggvasson (recorder), Bill Miller, Fritz Prinz, Marshall Jones, Robert Clark, Galip Ulsoy, Jim Duderstadt**

3. **Pam Eibeck (moderator), Deba Dutta (recorder), Andrew Alleyne, Bob Warrington, Norm Fortenberry, Rohan Abeyaratne, Ward Winer, Tom Perry**

NSF colleagues will also participate as observers

"5XME"
The Need for a Renaissance in in Engineering Education – BS to PhD

Adnan Akay
Civil, Mechanical and Manufacturing Innovation Division
National Science Foundation

Outline

I. Report from 2002 Workshop "Redefining ME"
   – Issues addressed
   – Recommendations
II. Renaissance in Engineering PhD Education
   – Status
   – Economics of PhD Education
   – Added value
   – Desired Attributes
III. Depth and Breadth
IV. Recommendations for 5XME

Workshop 2002 "Redefining ME"

Align the relationship between ME and key emerging technologies.

Explore the ways by which ME education and research can speed the natural evolution of these technologies.

Ensure that ME remains attractive to the best and the brightest students and faculty, including women and other traditionally underrepresented groups.

Core Areas Covered

- Micro/Nano Technology
- Biotechnology
  - Cellular and molecular biomechanics
- Information Technology
- Ecology and Energy

In each area implications for ME curriculum were identified.

Overarching Strategies

- Broaden the scope of ME core disciplines to enable the *real impact* of emerging technologies
- Develop support for ME faculty to move into new fields at all levels of their careers.
- Continue to produce agile graduates.
- Focus on *systems aspects* that are crucial to emerging technologies.
- Provide leadership for development of modernized, adaptable educational materials.

Overarching Action Items & Suggested Assignments

- Re-examine BS degree requirements in ME (ME Dept Heads).
- Benchmark university organizational structures for interdisciplinary research and education (ASME).
- Establish the means to develop and share best practices in the country and the world (ME Dept Heads).

Follow up

"New Directions and Opportunities in ME"

ASME Conference, April 2002

ME Department Heads

….since then

- The world has become flatter
- Innovation has gained more significance
- The number of engineering graduates elsewhere has increased
- The need for a new kind of engineer emerged…

Globalization, new technologies, and the rise of competitive engineering have placed increasing demands on universities to educate *a new kind of engineer*

The focus for change has been on engineering undergraduate education.

A near-complete silence on doctoral programs.

5XME WORKSHOP 10-11 MAY 2007 NATIONAL SCIENCE FOUNDATION

Some Reasons for the Silence

- Much fewer PhD students than UG students
- Role of PhD students within the academic research enterprise – breadth is distraction
- The current model has made the US graduate education the best in the world

S&E PhD Education and Technological Superiority – A Symbiotic Relationship

Graduate engineering education contributes directly to the broader national goals of technological and economic development

Provides future researchers, technology leaders and faculty.

“Graduate schools of science and engineering are … an indispensable underpinning of national strength and prosperity”

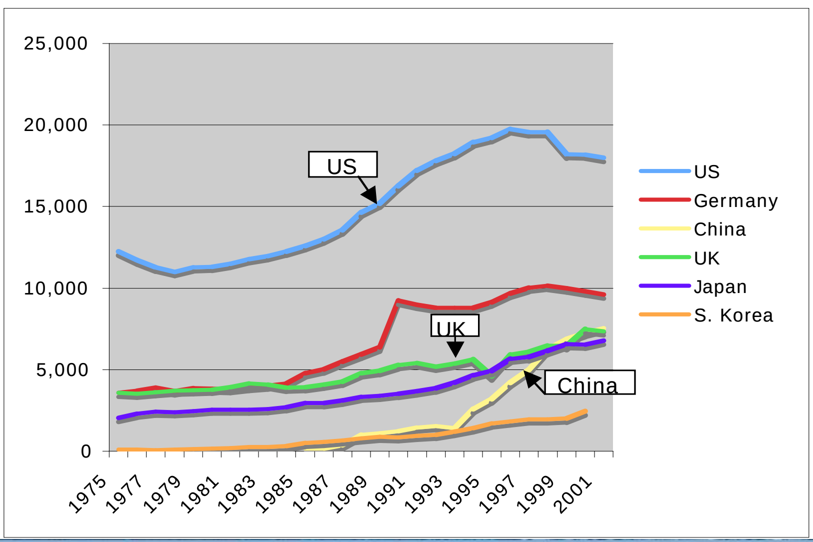
“The Best Education in the World”

- Attracts the best and the brightest from around the world
- Employs 70% of the world’s Nobel laureates
- Includes the highest ranked universities in the world
- Ranked first in technology and innovation, in technological readiness, in company spending research and technology

Inherent value or lack of competition?

The Economist

Science & Engineering PhD Degrees



Source: Science and Engineering Indicators 2004, National Science Foundation, Washington, DC

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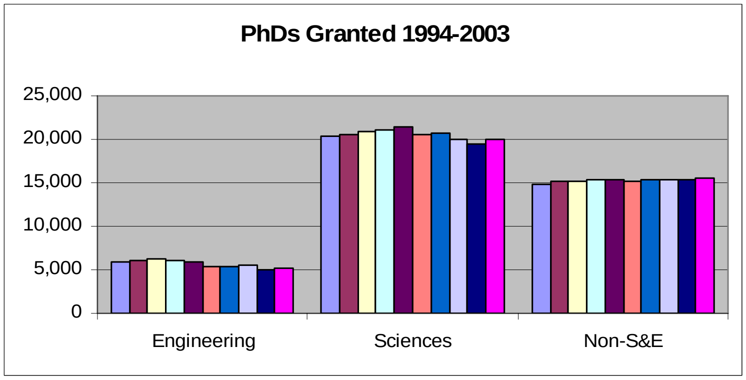
The Technology "Race"

- China, India, and Russia have the three highest GDP growth rates
- Patent applications
  - in China, South Korea, and Japan has risen by 24%
  - In the same time period, the patent application growth rate in the U.S. is at 3.8%

The US still provides the most nurturing environment required for innovation.

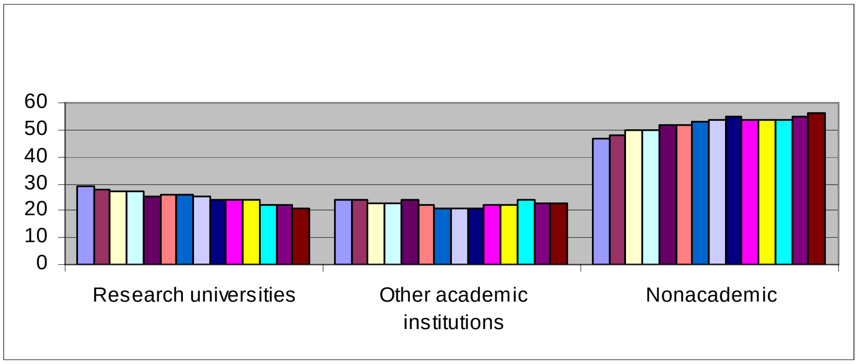
However, there are indications that other nations are starting to attract talent that U.S. universities previously had no trouble recruiting

Numbers



5,000/Yr ENG PhDs out of a total of 40,000 / Yr in all fields

S&E Doctorate Holders in the US
1975 – 2001 (Percent)



How well are they prepared?

Are there missed opportunities?

Perceptions & Criticisms

- Non-Academic Employers
  - PhD students are educated and trained too narrowly
  - They lack key professional skills
    - effective collaboration, working in teams,
    - organizational and managerial skills;
    - appreciation of applied problems;
    - knowledge *and culture* of other fields
- Academic Employers (Teaching institutions)
  - Ill-prepared to teach
- National policy makers
  - Too long to complete their degrees
- Current and former students
  - Ill-informed about non-academic employment opportunities

Nerad 2004, Griffiths – Reshaping Grad Ed

Three Overarching Themes

- Economics of PhD education
- Recruitment of PhD students
- Added-value of PhD education

Comparison Financing Professional Degree Students

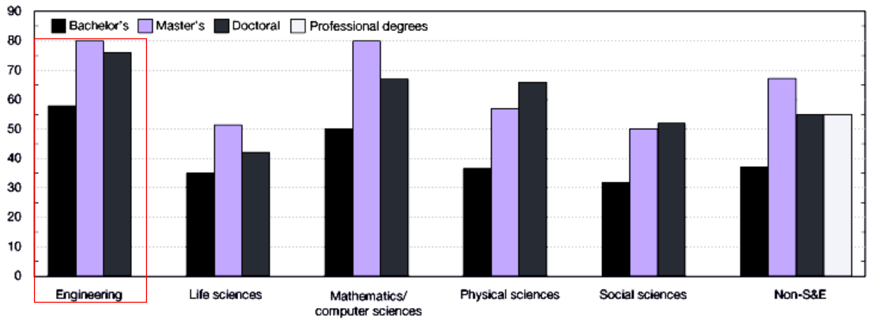
	% Receiving Research/Teaching Assistantship	% Receiving Federally Guaranteed Loans
MBA Student	12.6	44.1
Medical Student (MD)	7.5	78.3
Law Student (J.D)	7.0	82.3
Eng. PhD Student	67.9	7.6

Recruitment

- First-time graduate enrollment of foreign students between 2001 – 2004 decreased by 26%
- Ratio of foreign students:
  - 2001 63%
  - 2004 50%

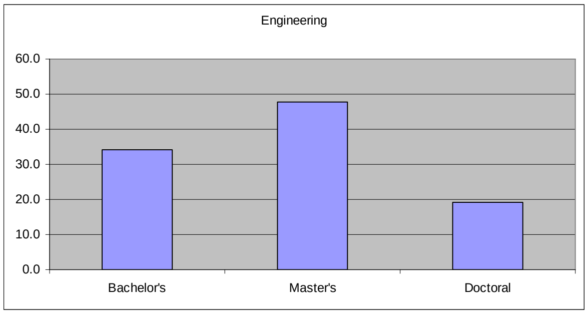
Valuation of a PhD Degree

Figure 3-8
Median salaries of degree recipients 1–5 years after degree, by field and level of highest degree: 2003



NOTE: Non-S&E fields include the SESTAT categories of "non-S&E" and "S&E-related."
SOURCE: National Science Foundation. Division of Science Resources Statistics, National Survey of College Graduates, preliminary estimates (2003)
Science and Engineering Indicators 2006

Inflation-Adjusted Change in Median Salary 1–5 years After Degree
(1993-2003)



Desired Attributes of a PhD

Results of an Informal Survey

- World class knowledge in some specialty
- Ability to develop world class knowledge in related areas
- Understanding how their specialized knowledge fits within the larger context of knowing and understanding.
- Aware of *all* effects of globalization and technology – and the price with which it comes.
- Leadership, as reflected in breadth of knowledge and ability to articulate ideas, confidence, poise, and focus.
- Can deal with predicaments and not just problems
- A thinker, a strategist

A Renaissance PhD

Challenges to Broader Preparation

- Requires breadth of knowledge and expertise that most advisors may not possess.
- Takes away student time from research project, which
  - provides financial aid to student
  - has to produce to meet deadlines
- No clear incentives or road-map for the education providers to make changes
- Students are self-selected, assisted by
  - Admission requirements
  - Types of perceived employments that await them

5XME WORKSHOP 10-11 MAY 2007 NATIONAL SCIENCE FOUNDATION

Depth vs. Breadth

- Loss of technical content
- Potential loss of desirable students
- Loss of focus on research
- Loss of research funds

Major Discoveries and Breakthroughs

- Major discoveries were made by scientists who were not highly specialized but by those who internalized considerable scientific diversity
- A necessary condition for making major discoveries….scientist internalize a high level of cognitive complexity.

R. Hollingsworth

Breadth & Depth
Cognitive Complexity

"High cognitive complexity is the capacity to observe and understand in novel ways the relationship among complex phenomena, the capacity to see relationships among disparate fields of knowledge. And it is that capacity which greatly increases the potential for making a major discovery."

"Cognitive complexity a better predictor of major discovery than measures of intelligence."

R. Hollingsworth

Enhancing Cognitive Complexity

- Internalization of multiple cultures
- Having non-scientific avocations

"Highly recognized scientists in many fields were quite talented as writers, musicians, painters, sculptors, novelists, essayists, philosophers and historians."

Preparing Renaissance Engineers

Value the Individual

- Multiple intelligences*
  - Musical intelligence
  - Bodily-Kinesthetic intelligence
  - Logical-Mathematical intelligence
  - Linguistic intelligence
  - Spatial intelligence
  - Interpersonal intelligence
  - Intra-personal intelligence
  - Naturalist intelligence
  - Existential intelligence
- Customized (individualized) education
- Flexibility

"Train a child according to his (her) way." *(Book of proverbs 22:6)*

*H. Gardner

Some Suggestions

- Flexible programs – Introduce incentives to faculty and students to include studies in areas of interest and talent
- Minors, modules, apprenticeships – management, sciences, psychology, finance, negotiations…..
- Intensive short training sessions – communications, management, business plan development,…..
- It is imperative for the community to re-examine the current model of PhD Education
- Broaden the basis of incoming students

Community Responsibility

- Government
  - In proposals require plans for educating PhD students
  - Support systemic changes in PhD education
- Industry/Business
  - Participate in the education enterprise – fellowships, apprenticeships
- Professional Societies
  - Need to go through a Renaissance of their own
- Academe
  - Reduce the conflict between institutional needs (teaching & research) and PhD education
  - Establish clear incentives for PhD education – separate from research
  - Ignore or improve USNWR ranking methods
- Faculty
  - Awareness of how important PhD education is to the well being of the nation.

"Blue-collar" PhDs or Thought Leaders

Students and the education providers have different interests and talents

PhD Education can take advantage of these rich differences.

The best time to improve is when one is still the best – a maxim that Detroit missed in the 1950s.

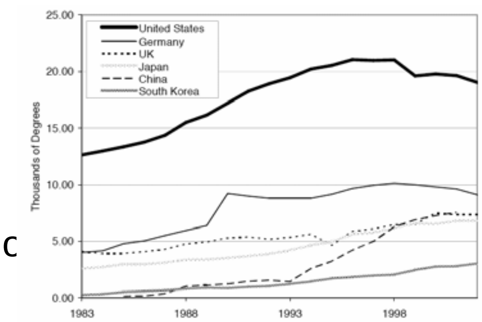
Thank you.

National Research Council Panel on Benchmarking the Research Competitiveness of the U.S. in Mechanical Engineering

Ward O. Winer
Georgia Institute of Technology

Study Context

- Globalization and international competitiveness
- Changing S&E culture
- Technical innovatic



Statement of Task

1. What is the current position of U.S. mechanical engineering research relative to that of other regions or countries?

2. What key factors influence US performance in mechanical engineering?

3. On the basis of current trends in the United States and abroad, what will be the relative U.S. position in the near term and in the longer term?

Supported by NSF

Study Process

- Ad hoc panel of 11
- The group met one time in person, and otherwise met via teleconference.
- Final report coming this summer.

The Panel

Ward O. Winer (NAE), Chair, Georgia Institute of Technology
Cristina H. Amon (NAE), University of Toronto
L. Catherine Brinson, Northwestern University
Earl H. Dowell (NAE), Duke University
John R. Howell (NAE), The University of Texas
Marshall G. Jones (NAE), GE Corporate Research and Development
Chang-Jin "CJ" Kim, University of California, Los Angeles
Kemper E. Lewis , University of Buffalo
Van C. Mow (NAE, IOM), Columbia University
J. Tinsley Oden (NAE), The University of Texas
Masayoshi Tomizuka, University of California, Berkeley

Tina Masciangioli, NRC Staff Officer

Areas of Mechanical Engineering Used in the Study

Acoustics and Dynamics
Bioengineering
Computational Mechanics
Design/CAD
Dynamic Systems and Controls
Energy Systems
Manufacturing/CAM
Mechanics of Engineering Materials
MEMS/NEMS
Thermal Systems and Heat Transfer
Tribology

Examples of Sub-Areas of Mechanical Engineering Used in Study

ACOUSTICS & DYNAMICS

Acoustics
Nonlinear Phenomena
Computational Models
Experimental Methods
Complex Systems

TRIBOLOGY

Hydrodynamic phenomena (inc. hydrostatic and elastohydrodynamic lubrication with liquids and gases, seals)
Friction and wear
Tribomaterials (inc. liquid, gas, and solid lubricants; fatigue)
Contact mechanics and surface engineering (inc. nanoscale effects)
Diagnostics of tribosystems

1. What is the current position of U.S. mechanical engineering research relative to that of other regions or countries?

Publications
Citations

Citations per Paper
Publications in Top Journals

Most Highly Cited Papers and Authors
Virtual Congresses
Awards

Sources :
Thomsen ISI Essential Science Indicators
NSF Science and Engineering Indicators

Virtual World Congresses

- Specialized Imaginary Meetings in ~5 sub-areas for each of our 11 major areas of mechanical engineering
- 8-10 organizers (leading mechanical engineers in each sub-area) each selected 20 speakers (scientists or engineers they'd invite to their meeting)

Leadership Assessments

Use data on most cited papers, hot papers, and virtual congresses to assess research leadership in areas of mechanical engineering:

- 75 percent or more – the strong leader
- 50-75 percent – the leader
- 30-50 percent – among the leaders
- < 30 percent – lagging behind the leaders

Example: Tribology

Subareas

Contact Mechanics and Surface Engineering	53%	
Diagnositcs of Tribosystems	37%	
Friction and Wear	46%	
Hydrodynamic Phenomena	45%	
Tribomaterials	52%	
Subarea average		48%

Most-cited articles in *Wear**

1995	1997	1999	2001	2003	2005
26%	34%	14%	12%	22%	34%

Note: other journals will be analyzed

Conclusion: U.S. among the leaders

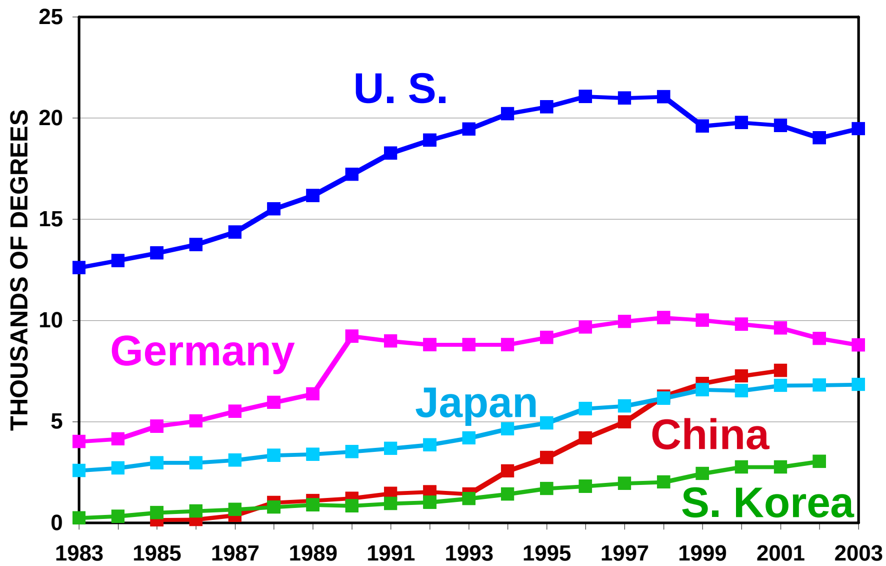
Tribology Article count#: 1999 (35%), 2003 (32%), 2005 (33%)

#*average of contributions to: Journal of Tribology*, *Tribology Transactions*, *Wear*, *Tribology International*, *Tribology Letters*

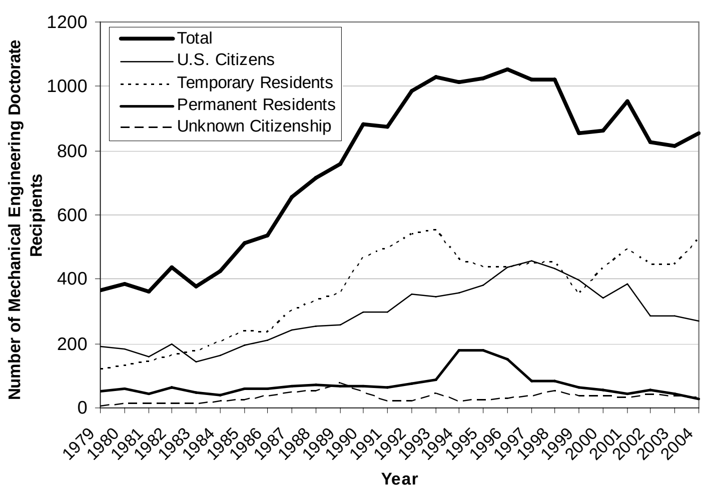
2. What key factors influence U.S. performance in mechanical engineering?

- **National imperatives:** Historical events and policy decisions that have influenced leadership in mechanical engineering.
- **Innovation:** Investment and technology development mechanisms that facilitate introduction into the marketplace of new technology derived from mechanical engineering research.
- **Major facilities, centers, and instrumentation:** The physical infrastructure and materiel for conducting mechanical engineering research.
- **Human resources:** The national capacity of mechanical engineering students and degree holders.
- **Funding:** Financial support for conducting mechanical engineering research.

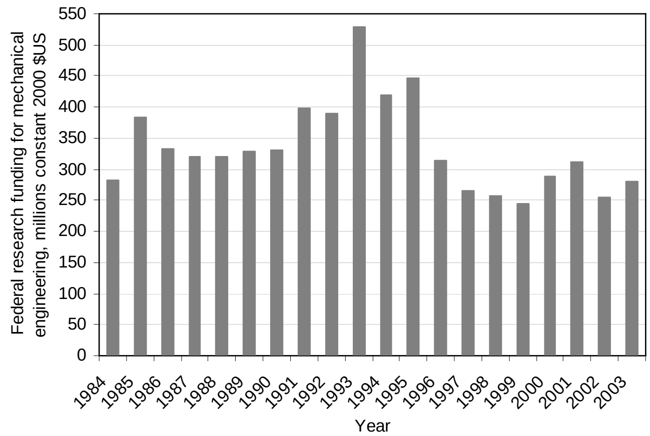
Example: S&E Doctoral Degrees



Example: Mechanical Engineering PhDs earned in the U.S.



Example: Federal Research Funding for Mechanical Engineering



Final Step of the Study

On the basis of current trends in the United States and abroad (publication rates, human resources, research funding, etc.), what will be the relative U.S. position in the near term and in the longer term?

Thank You!

For more information:

Ward O. Winer
Georgia Institute of Technology
ward.winer@me.gatech.edu

Or

Tina M. Masciangioli
Board on Chemical Sciences and Technology
tmasciangioli@nas.edu

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Globalization and Engineering Education

Nariman Farvardin, Dean
A. James Clark School of Engineering

UNIVERSITY OF MARYLAND

"Where once nations measured their strength by the size of their armies and arsenals, in the world of the future knowledge will matter the most." President Bill Clinton." Commencement address, Morgan State University, 1997

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Outline

- A series of apparently disparate observations
- A few recommendations

Caveats

- My thoughts are general and not specifically related to Mechanical Engineering
- Do not expect any bomb shells or major surprises; maybe one or two controversial recommendations

Report of the 5XME Workshop

- Discusses the need for a transformation in mechanical engineering education, focusing on the following attributes for ME graduates
  - Broad grounding in fundamentals
  - Flexibility and agility
  - Innovation and creativity to benefit society
  - Global focus
  - Teamwork and leadership
  - Communication skills

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Report of the 5XME Workshop

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  - Global focus
  - Teamwork and leadership
  - Communication skills

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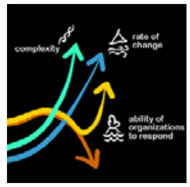
Observations

1. Rate of change
2. Globalization
3. Technology trends
4. The Internet



Observation #1: Rate of Change

Shift happens and it happens faster than before

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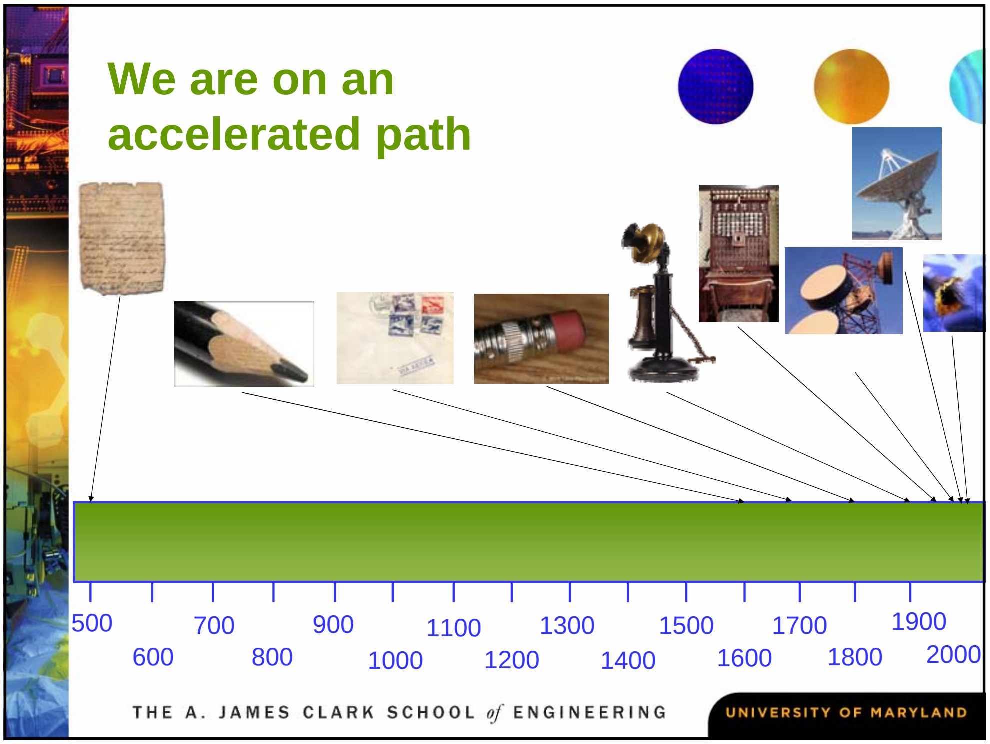
We are on an accelerated path
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
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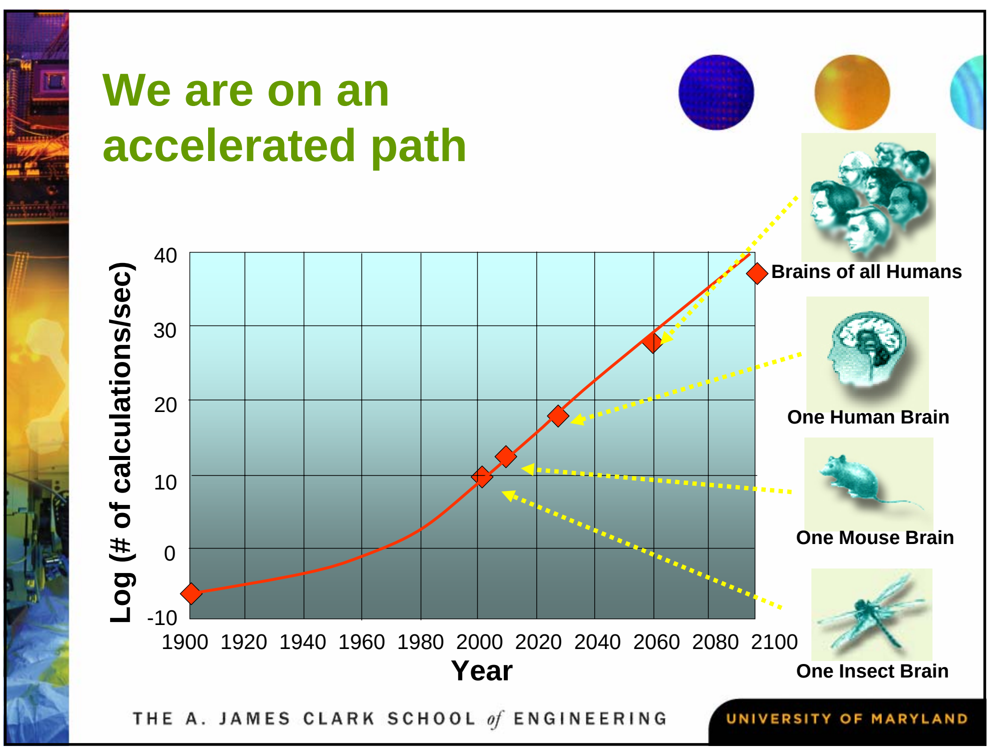
We are on an accelerated path
Log (# of calculations/sec)
40
30
20
10
0
-10
1900 1920 1940 1960 1980 2000 2020 2040 2060 2080 2100
Year
Brains of all Humans
One Human Brain
One Mouse Brain
One Insect Brain
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Name This Country

- Richest in the world
- Largest military
- Center of world business and finance
- Strongest education system
- World center of innovation and invention
- Currency the world standard of value
- Highest standard of living

England in 1900

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Observation 2: Globalization

The World Is Flat

Globalization

- Globalization is a fact of life
- Talent, capital and knowledge travel where the opportunities are
- Competition will continue to get tougher
- Understanding other cultures, learning other languages and appreciating how other people do business becomes increasingly important

Globalization

- Attracting brilliant graduate students from abroad has become more difficult
- Foreign nationals who complete graduate education in the US pursue career opportunities outside the US in large numbers

Globalization

- In the global economy, the winners are those who can generate **intellectual property** and successfully commercialize it, wherever they can
- Developing and retaining technology leaders will be a key factor

Globalization

- Who can afford to invest the resources (human capital and infrastructure) to stay at the cutting edge?
- Universities will have a much bigger role than ever before in terms of their research mission
- Governments that value "basic research" will be able to promise a better life for their citizens

Observation #3: Technology Trends

Technology Trends

- Engineering Principles Applied to Biological Systems and Health Care
  - Biomedical devices, health monitoring systems, targeted drug delivery, IT-based health management systems, synthetic biology for energy generation
- Energy Generation and Storage
  - Fuel cell systems, advanced batteries, super capacitors, thin film and organic solar energy conversion, biological processes for fuel production, next generation nuclear reactors, fusion

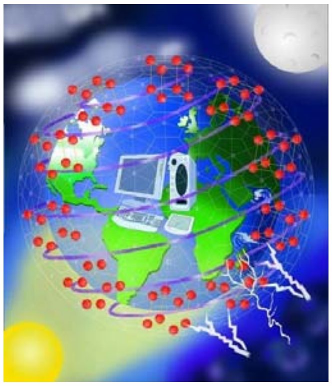
Technology Trends

- Miniaturization
  - Electronics, display technologies, sensors/actuators, novel materials, small air and land vehicles
- Information Technology
  - Wireless broadband, multimedia systems, visualization technologies, data mining, intelligent transportation systems, ubiquitous use of RFIDs, applications to health care

Technology Trends

- Success requires a cross-disciplinary approach involving engineers (various flavors), computer scientists, biologists, medical doctors, physicists, chemists, mathematicians, sociologists, economists, …

Observation #4: The Internet



The Internet

- ~1-10 exabytes (10**18 bytes) of unique information will be generated world wide this year
- This is estimated to be more than what was generated in the past 5000 years.

The Internet

- Youngsters have a shorter attention span
- They learn by doing rather than by listening
- Access to information has become ridiculously easy
- Sifting the good from the bad is becoming harder
- New ethical issues are emerging

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Thoughts on how to cope with these issues

Recommendations

1. Place emphasis on the quality of engineering graduates and not exclusively their numbers
2. Re-establish the lost prestige of an “engineering degree”
3. Make the “masters degree” the first professional engineering degree
4. Drastically increase the number of domestic students who pursue a Ph.D. degree in engineering

Recommendations

5. Modern engineering education must include
   - "quantitative biology" as a core component of engineering education
   - cultural diversity, language skills, and international business
   - technology entrepreneurship
   - cross-disciplinary thinking and working
   - Tools to access gigantic repositories of knowledge
   - Ethics, especially the ethics of the Internet

Recommendations

6. We need an agile and dynamic engineering education—one that keeps a core of fundamentals but maintains a flexible component to keep it relevant and up-to-date
7. We need to ensure that the cultural gap between teachers and students does not become an impediment to learning

Traditional vs. Modern Engineer

Traditional Engineer

- Problem solver
- Excellent mastery of technical skills
- Understands technical context of work
- Is content doing all her/his work in one country
- Reports up the management chain to MBA

Modern Engineer

- Problem finder and solver
- Combines technical skills with soft skills
- Understands the market too
- Thrives on international relations and business opportunities
- Hires MBAs

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21st Century Engineering

The Challenge of Change

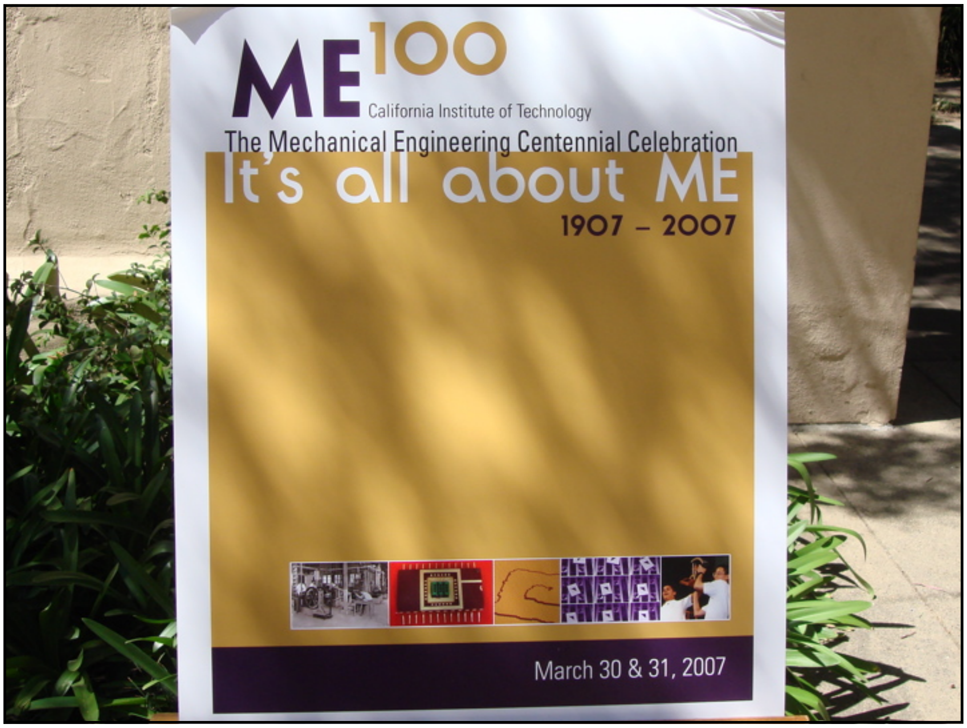
- The changing workforce and technology needs of a global knowledge economy are changing engineering practice demanding far broader skills.
- Importance of technological innovation to economic competitiveness and national security is driving a new priority for application-driven basic engineering research.
- Challenges such as out sourcing and off shoring, decline of student interest in STEM careers, inadequate social diversity, and immigration constraints are raising serious questions about the adequacy of current national approach to engineering.

Engineering Practice

Engineering Research

Engineering Education


CALTECH


ME100
California Institute of Technology
The Mechanical Engineering Centennial Celebration
It's all about ME
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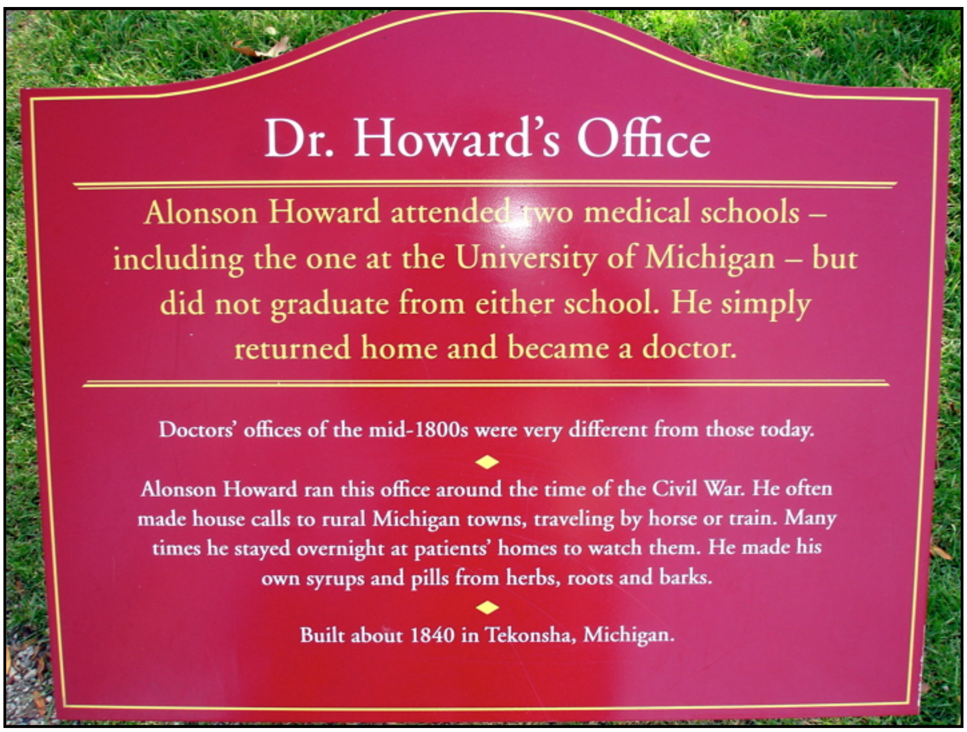
March 30 & 31, 2007


CALTECH

An Interesting Comparison:
Medicine
…at the turn of the last century




Ext. Butternu Bark.
Ext. Boneset
WGS

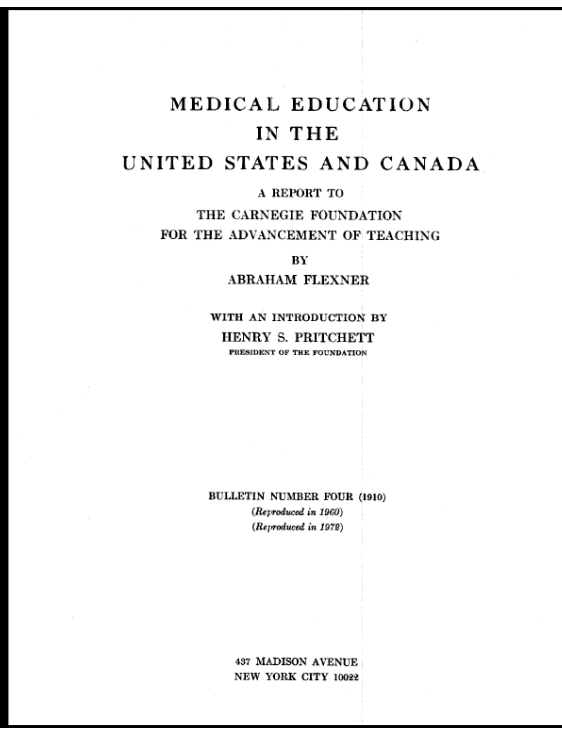

Ext. W. Snake Root.
Ext. Skunk Cabbage.
Ext. Skunk Cabbage.

The Medical Profession

- During the 19th century medical education had evolved from a practice-based apprenticeship to an entirely didactic (lecture-based) education.
- To become a doctor, one needed only a high school diploma, a year of lectures, and a few dollars for a license to begin practice as a physician.
- The changing health care needs of society, coupled with the changing knowledge base of medical practice, would drive a very rapid transformation of the medical profession, along with medical education, licensure, and practice.

The Flexner Report

- The Carnegie Foundation commissioned noted educator Abraham Flexner to survey 155 medical schools and draft a report on the changing nature of the profession and the implications for medical education.
- The key to his study was to promote educational reform as a public health obligation: “If the sick are to reap the full benefit of recent progress in medicine, a more uniformly and expensive medical education is demanded."



MEDICAL EDUCATION
IN THE
UNITED STATES AND CANADA

A REPORT TO
THE CARNEGIE FOUNDATION
FOR THE ADVANCEMENT OF TEACHING

BY
ABRAHAM FLEXNER

WITH AN INTRODUCTION BY
HENRY S. PRITCHETT
PRESIDENT OF THE FOUNDATION

BULLETIN NUMBER FOUR (1910)
(Reproduced in 1960)
(Reproduced in 1972)

437 MADISON AVENUE
NEW YORK CITY 10022

Flexner's Impact

- The Flexner Report of 1910 transformed medical education and practice into the 20th century paradigm of scientific (laboratory-based) medicine and clinical training in teaching hospitals.
- Flexner held up Johns Hopkins medical school as the model (the existence proof) of the new approach, requiring a baccalaureate degree for entry, a teaching hospital for training, and a strong scientific foundation.
- Over the next two decades, two-thirds of all medical schools were closed, and those that remained were associated with major universities!

Oh, and by the way…

- Although he was primarily focused on medicine, Flexner raised very similar concerns about engineering education even at this early period.
- “The minimum basis upon which a good school of engineering accepts students is, once more, an actual high school education, and the movement toward elongating the technical course to five years confesses the urgent need of something more.”

A Flexner Report for Engineering?

- Mann Report (1918)
- Wilkenden Report (1923)
- ASEE Grinter Report (1955)
- ASEE Green Report (1994)
- NRC BEED Report and ABET EC2000
- NAE Engineering of 2020 (2004)
- Carnegie Foundation Study (2006)
- Bill Schowalter: “Appearance every decade of a definite report on the future of engineering education is as predictable as the sighting of the first crocuses in spring.” (2003)

Yet, despite these efforts

- Although engineering is one of the professions most responsible for profound changes in our society, its characteristics of practice, research, and education have been remarkably constant–some might suggest even stagnant–relative to other professions.
- Engineers are still used as commodities by industry, and engineering services are increasingly off shored.
- Engineering research is still misunderstood and inadequately supported by industry and government.
- "Most of our universities are attempting to produce 21st century engineers with a 20th century curriculum in 19th century institutions." (JJD)

The stakes are very high!!!

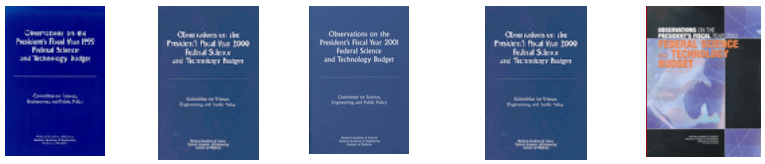
- An extrapolation of current trends such as the off shoring of engineering jobs and services, inadequate investment in long-term engineering research, inadequate innovation in engineering education, declining interest on the part of students in STEM careers, and immigration constraints raises very serious concerns.
- Without concerted action, America faces the very real prospect of losing its engineering competence in an era in which technological innovation is the key to economic competitiveness, national security, and social well-being.
- Bold and concerted actions are necessary to sustain and enhance the profession of engineering in America–its practice, research, and education!

The Approach: Roadmapping

- Engineering Today (“Where we are…”)
- Engineering Tomorrow (“Where we need to be …”)
- Gap Analysis (“How far we have to go…)
- The Roadmap (“How to get there…)

NAE-RAGS-NII-ACI… Reports

FS&T Reports to date



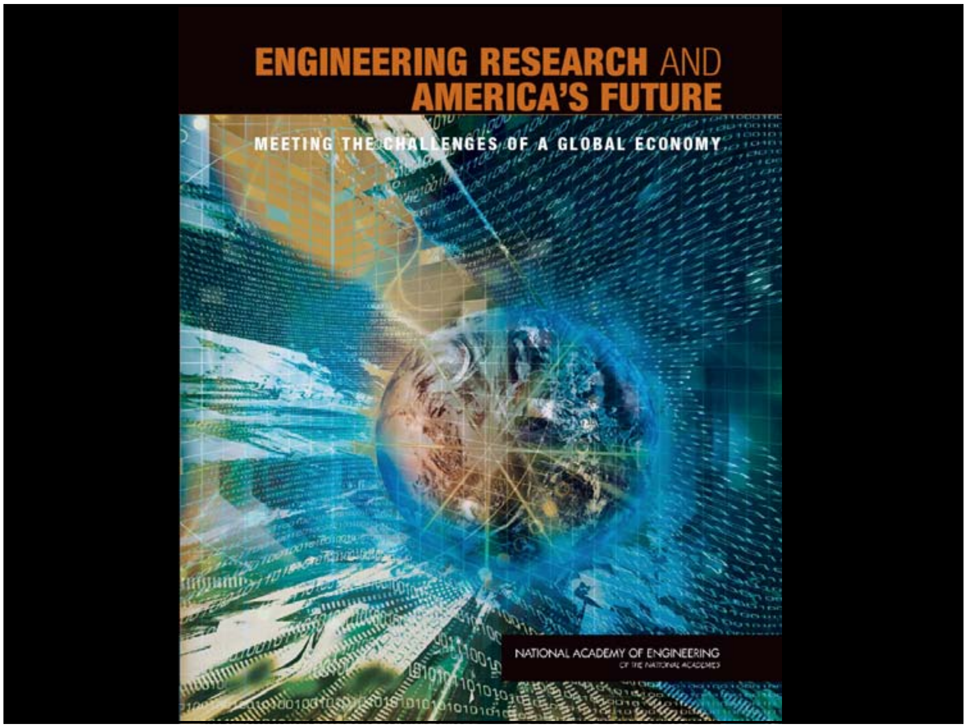
1999 2000 2001 2002 2003

CRITICAL CHOICES: SCIENCE, ENERGY, AND SECURITY

Final Report of the
Secretary of Energy Advisory Board's
Task Force on the Future of Science Programs
at the Department of Energy

October 13, 2003

Secretary of Energy Advisory Board
U.S. Department of Energy


ENGINEERING RESEARCH AND AMERICA'S FUTURE
MEETING THE CHALLENGES OF A GLOBAL ECONOMY
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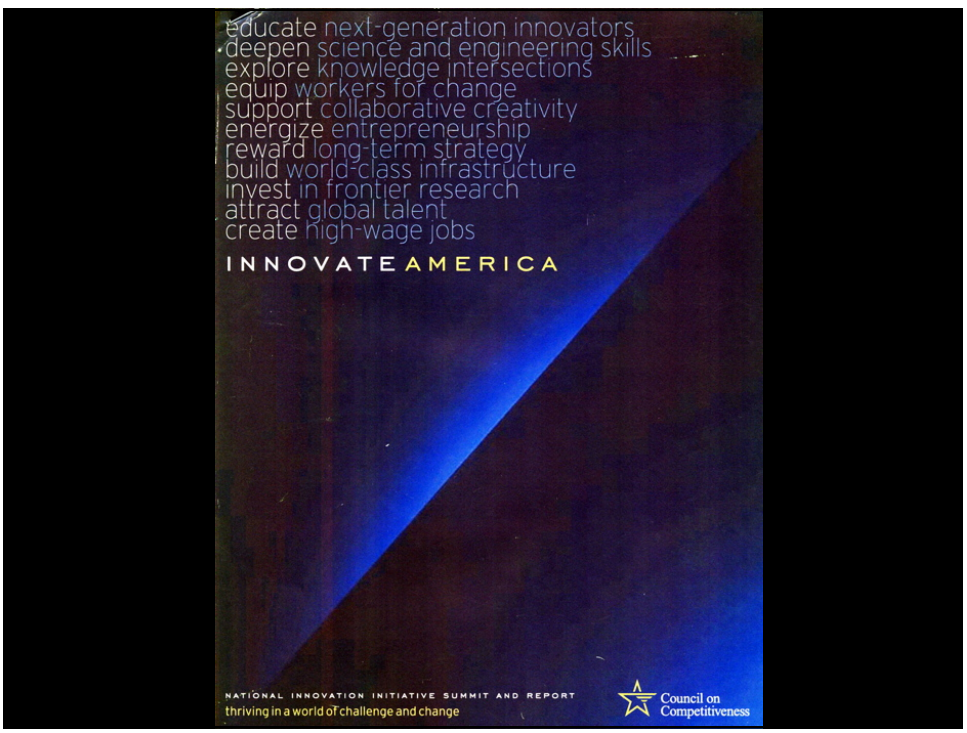
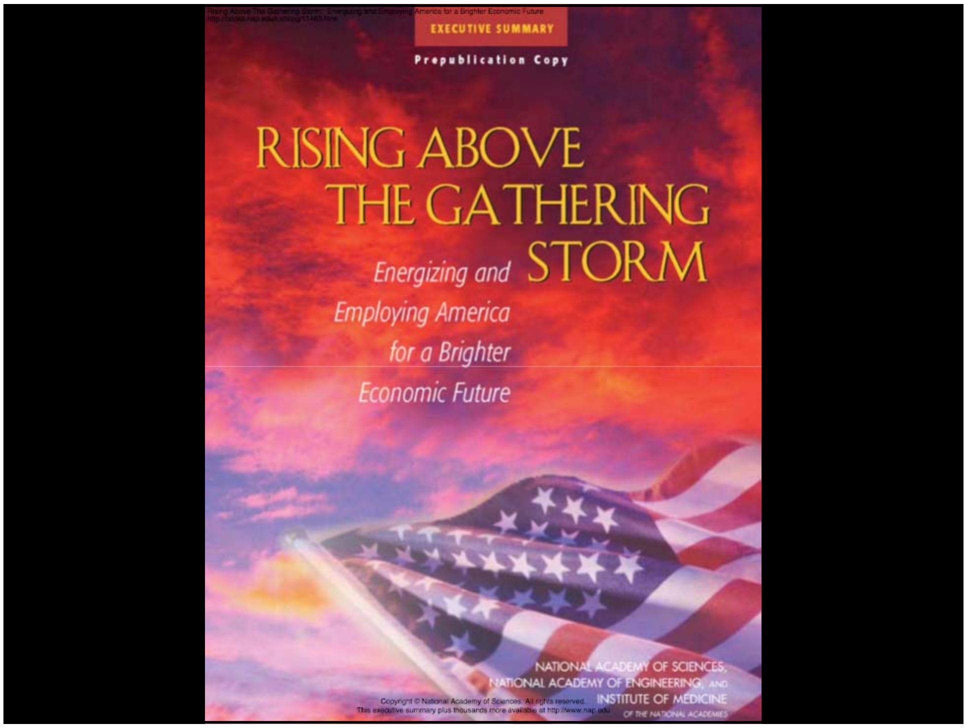

educate next-generation innovators
deepen science and engineering skills
explore knowledge intersections
equip workers for change
support collaborative creativity
energize entrepreneurship
reward long-term strategy
build world-class infrastructure
invest in frontier research
attract global talent
create high-wage jobs
INNOVATE AMERICA
NATIONAL INNOVATION INITIATIVE SUMMIT AND REPORT
thriving in a world of challenge and change
Council on Competitiveness



NEW HORIZONS FOR A FLAT WORLD

LEONARD LYNN
HAL SALZMAN

Collaborative Advantage

The days of U.S. technological domination are over. The nation must learn to thrive through working with others.

Michael Schochet, Currently Involution #7, Acrylic on canvas, 36 x 72 inches, 2004.

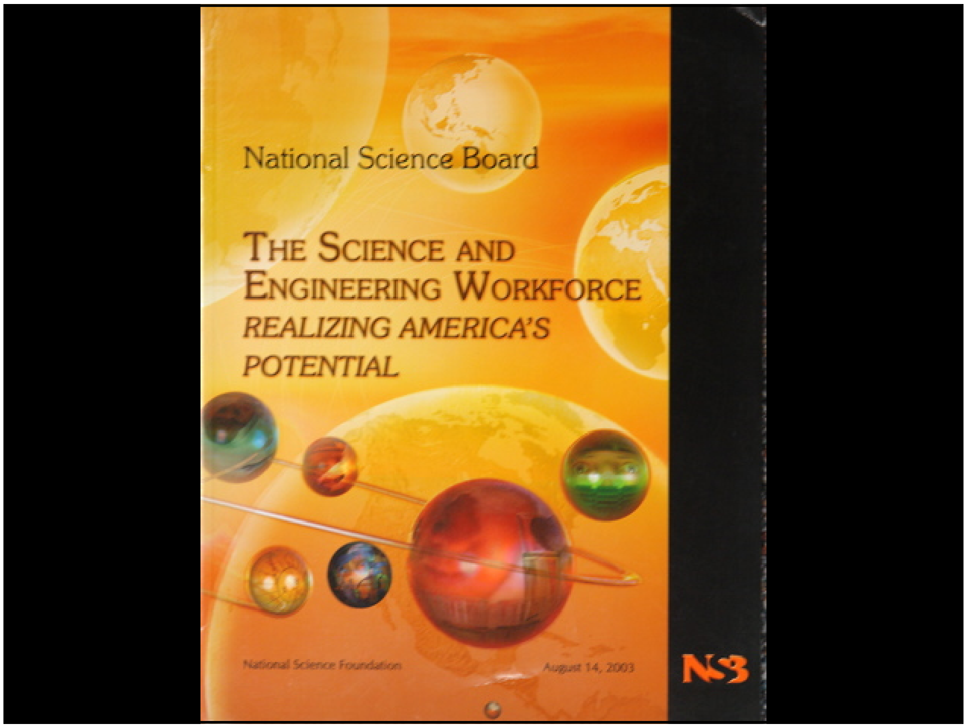
Almost daily, news reports feature multinational companies—many based in the United States—that are establishing technology development facilities in China, India, and other emerging economies. General Electric, General Motors, IBM, Intel, Microsoft, Motorola—the list grows steadily longer. And these new facilities no longer focus on low-level technologies to meet Third World conditions. They are doing the cutting-edge research once done only in the United States, Japan, and Europe. Moreover, the multinationals are being joined by new firms, such as Huawei, Lenovo, and Wipro, from the emerging economies. This current globalization of technology development is, we believe, qualitatively different from globalization of the past. But the implications of the differences have not sunk in with key U.S. decisionmakers in government and industry.

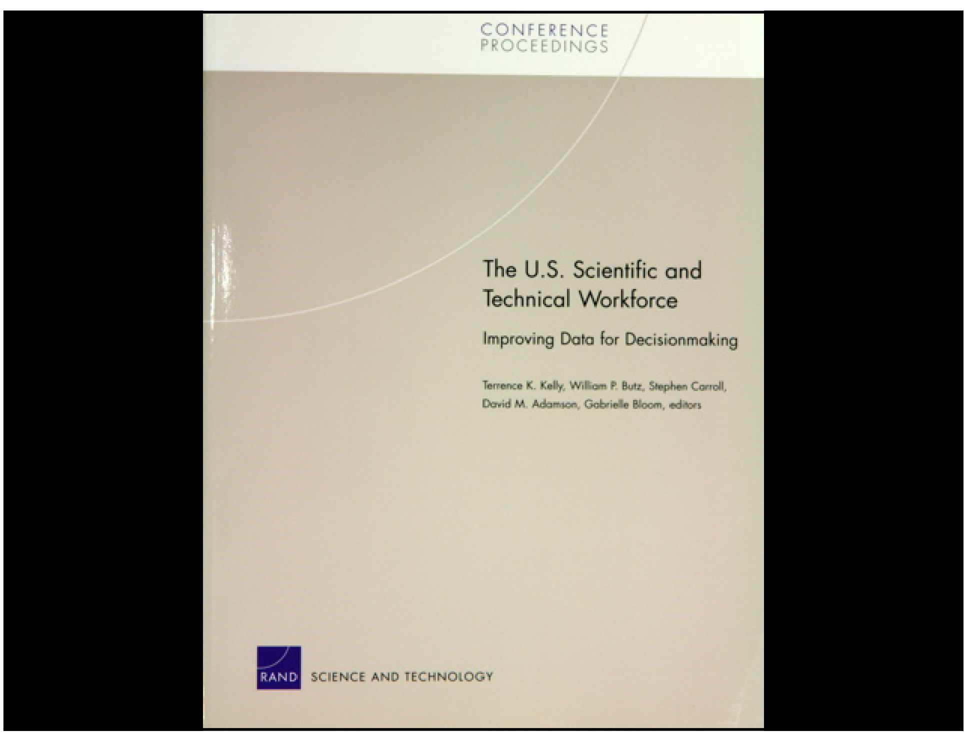
It is not that the new globalization has gone unnoticed. Many observers are concerned that the United States is beginning to fall into a vicious cycle of disinvestment in and weakening of its innovation systems. As U.S. firms move their engineering and R&D activities offshore, they may be disinvesting not just in their own facilities but also in colleges and regions of the country that now form critical innovation clusters. These forces may combine to dissolve the bonds that form the basis of U.S. innovation leadership.

A variety of policies have been proposed to protect and restore the preeminent position of U.S. technology. Some of these proposals are most concerned with building up U.S. science and technology (S&T) human resources by strengthening the nation's education system from kindergarten through high school; encouraging more U.S. students to study engineering and science, specifically inducing more women and minorities to pursue science and technology careers; and easing visa restrictions that form barriers to talented foreigners who want to enter U.S. universities and industries. Other proposals include measures to outbid other countries as they offer benefits to attract R&D activities. Still others call for funneling public funds into the

Issues in Science and Technology
(National Academies of Science: www.issues.org)
The research this paper is based on was generously supported by the National Science Foundation, Societal Dimensions of Engineering, Science, and Technology (SDEST) Program, Grant #0431755, and the Kauffman Foundation.

STEM Education Reports


National Science Board
THE SCIENCE AND ENGINEERING WORKFORCE
REALIZING AMERICA'S POTENTIAL
National Science Foundation
August 14, 2003


CONFERENCE PROCEEDINGS
The U.S. Scientific and Technical Workforce
Improving Data for Decisionmaking
Terrence K. Kelly, William P. Butz, Stephen Carroll, David M. Adamson, Gabrielle Bloom, editors
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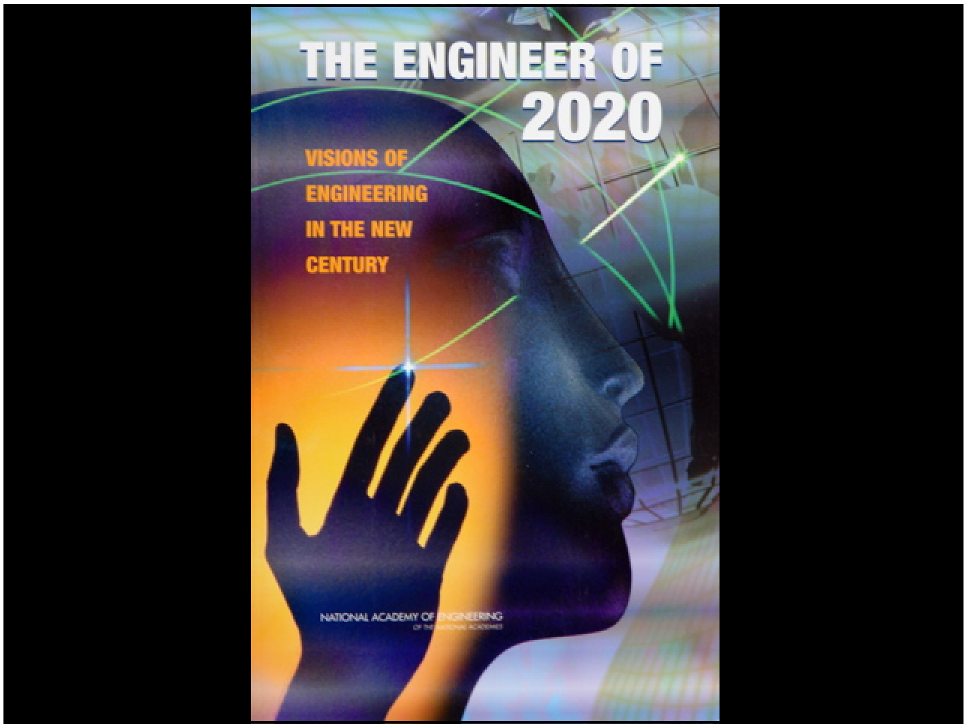
THE ENGINEER OF 2020
VISIONS OF ENGINEERING IN THE NEW CENTURY
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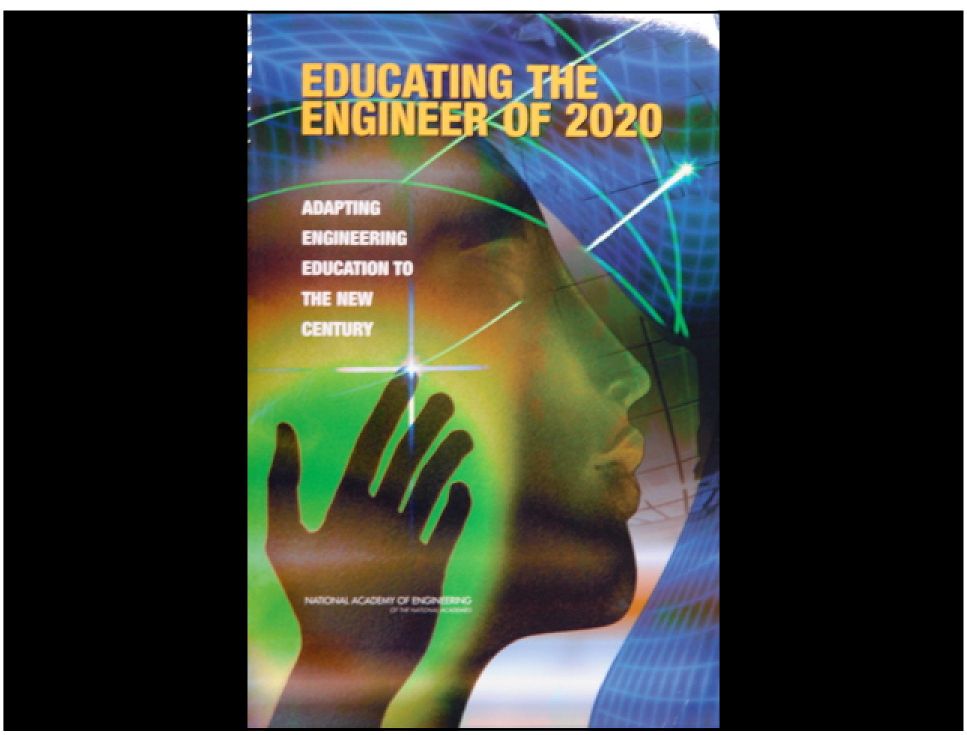
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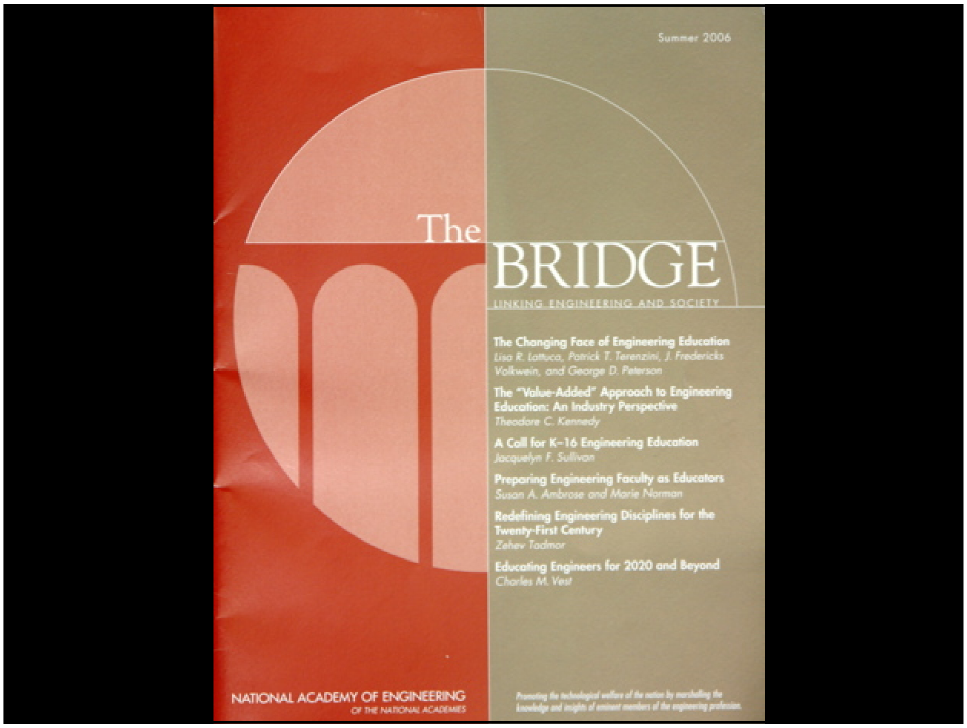

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The "Value-Added" Approach to Engineering Education: An Industry Perspective
Theodore C. Kennedy
A Call for K–16 Engineering Education
Jacquelyn F. Sullivan
Preparing Engineering Faculty as Educators
Susan A. Ambrose and Marie Norman
Redefining Engineering Disciplines for the Twenty-First Century
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Educating Engineers for 2020 and Beyond
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A Publication of
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SEEING THROUGH PRECONCEPTIONS: A DEEPER LOOK AT CHINA AND INDIA

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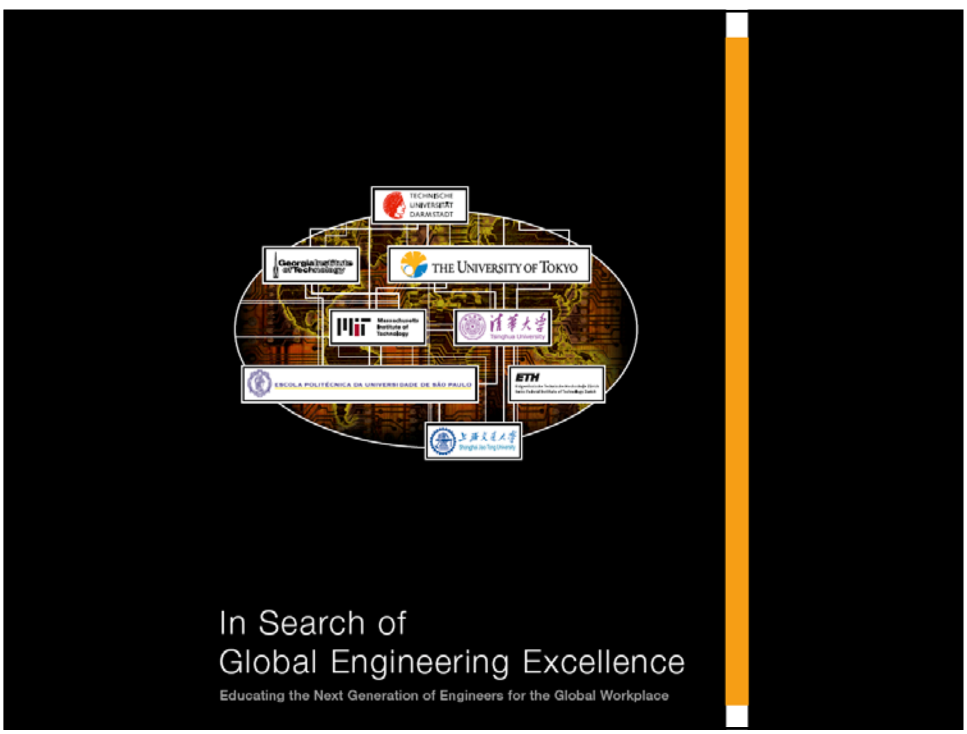
VIVEK WADHWA
GARY GEREFFI
BEN RISSING
RYAN ONG

Where the Engineers Are

To guide education policy and maintain its innovation leadership, the United States must acquire an accurate understanding of the quantity and quality of engineering graduates in India and China.

Although there is widespread concern in the United States about the growing technological capacity of India and China, the nation actually has little reliable information about the future engineering workforce in these countries. U.S. political leaders prescribe remedies such as increasing U.S. engineering graduation rates to match the self-proclaimed rates of emerging competitors. Many leaders attribute the increasing momentum in outsourcing by U.S. companies to shortages of skilled workers and to weaknesses in the nation's education systems, without fully understanding why companies outsource. Many people within and beyond government also do not seem to look ahead and realize that what could be outsourced next is research and design, and that the United States stands to lose its ability to "invent" the next big technologies.



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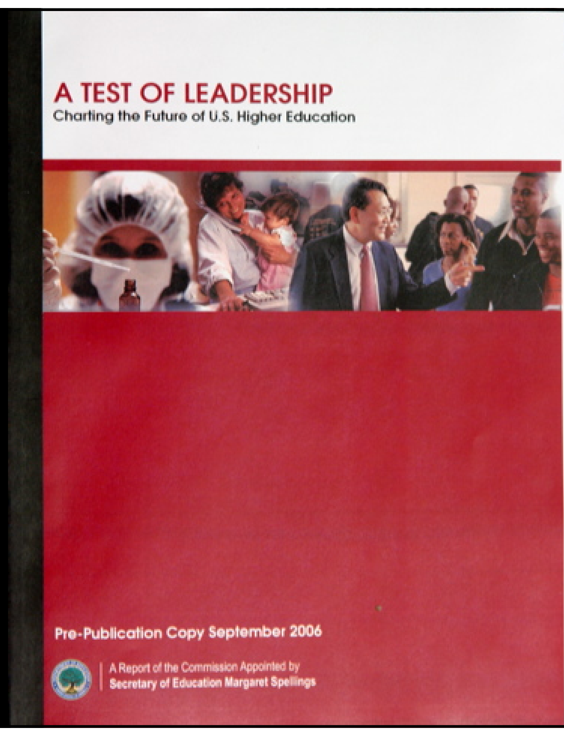
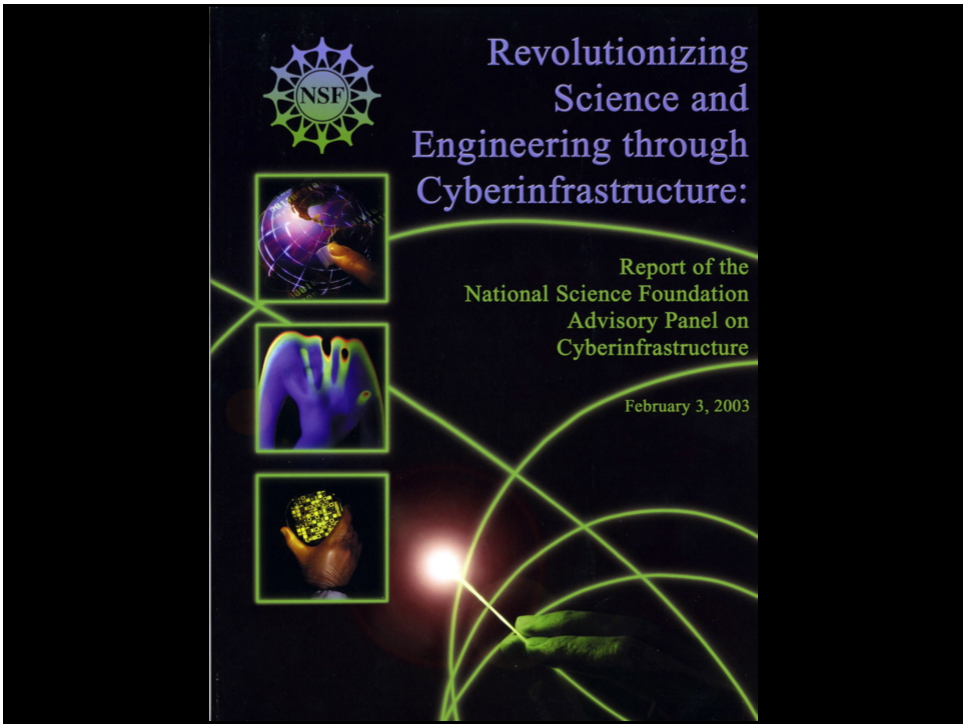
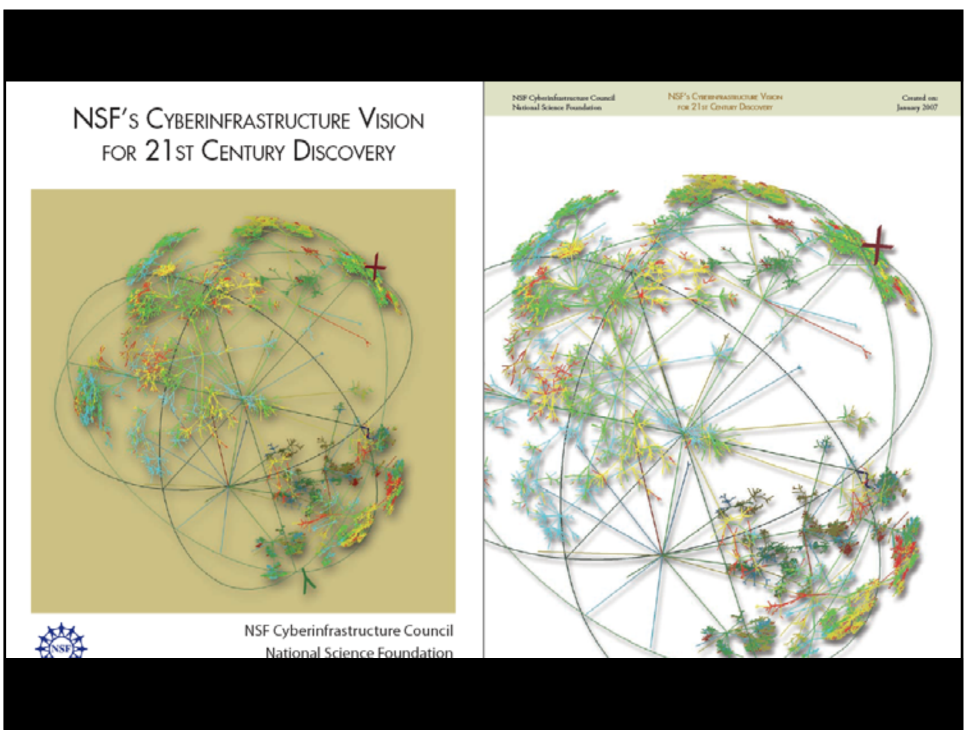
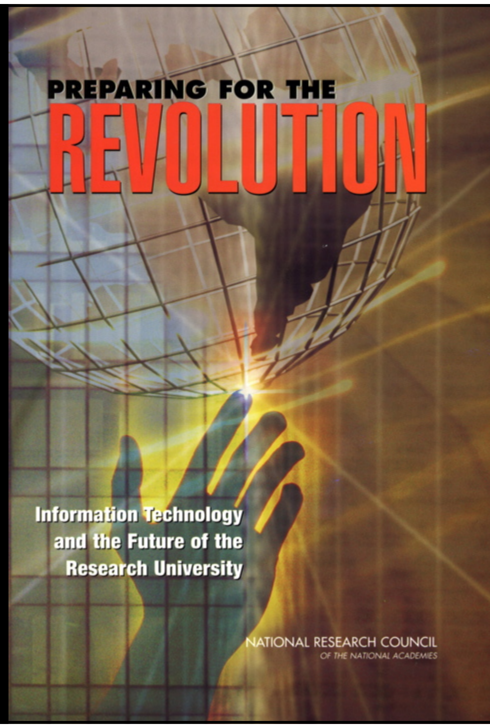



NSF
Revolutionizing Science and Engineering through Cyberinfrastructure:
Report of the National Science Foundation Advisory Panel on Cyberinfrastructure
February 3, 2003


NSF's Cyberinfrastructure Vision for 21st Century Discovery
NSF Cyberinfrastructure Council
National Science Foundation
NSF Cyberinfrastructure Council
National Science Foundation
Created on:
January 2007


PREPARING FOR THE
REVOLUTION
Information Technology
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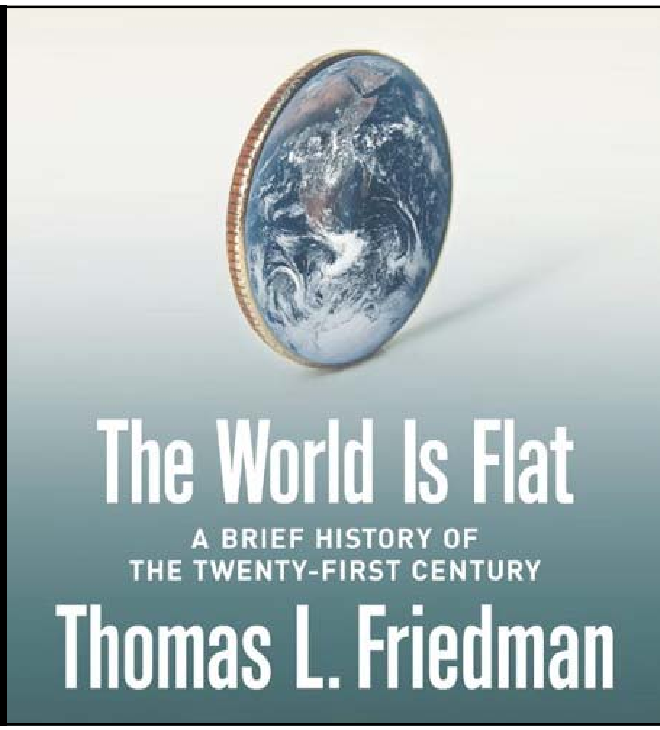
Engineering Today… and Tomorrow

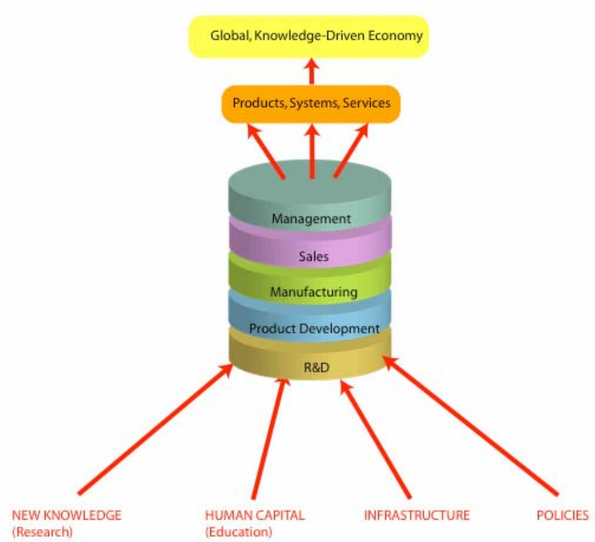
Engineering Practice

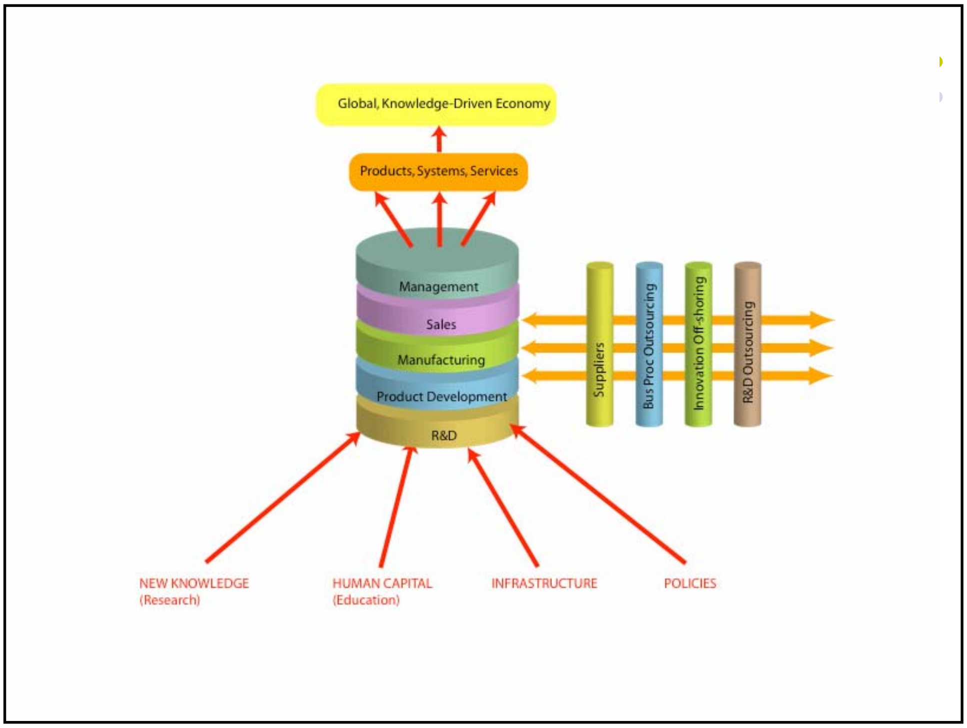
The Way the World Works Today



Innovation and Globalization

- A radically new system for creating wealth has emerged that depends upon the creation and application of new knowledge and hence upon educated people and their ideas.
- "Intellectual work and capital can be delivered from anywhere–disaggregated, delivered, distributed, produced, and put back together again…" (Friedman)
- "Some three billion people who were excluded by the pre-Internet economy have now walked out onto a level playing field, from China, India, Russia, and Eastern Europe, regions with rich educational heritages."

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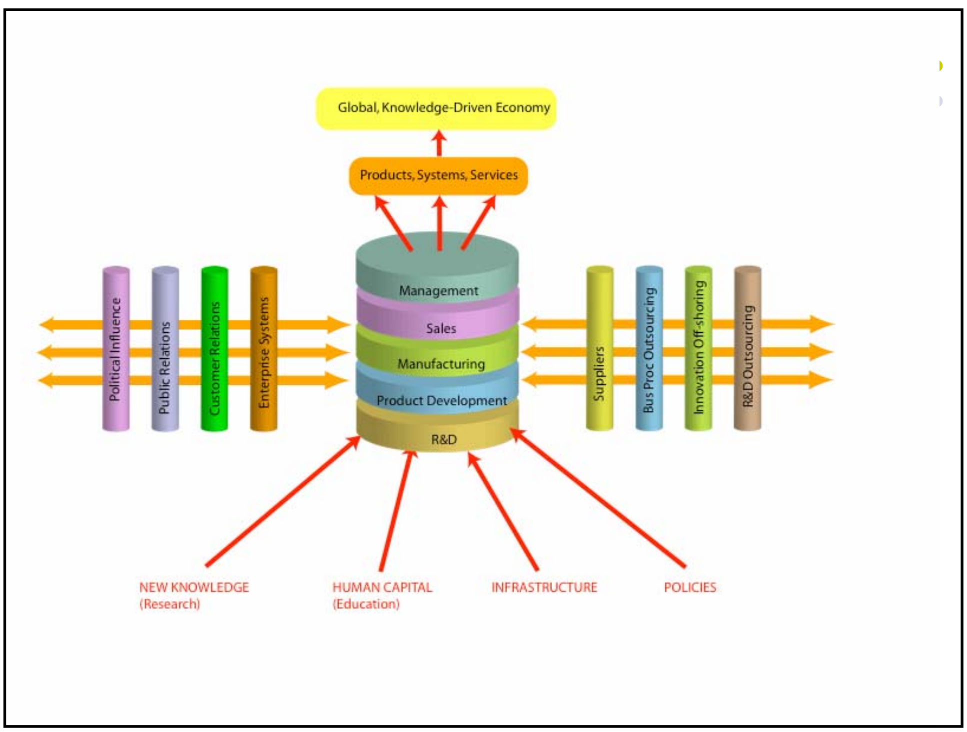
Products, Systems, Services
Management
Sales
Manufacturing
Product Development
R&D
Suppliers
Bus Proc Outsourcing
Innovation Off-shoring
R&D Outsourcing
NEW KNOWLEDGE (Research)
HUMAN CAPITAL (Education)
INFRASTRUCTURE
POLICIES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Political Influence
Public Relations
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Management
Sales
Manufacturing
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Innovation Off-shoring
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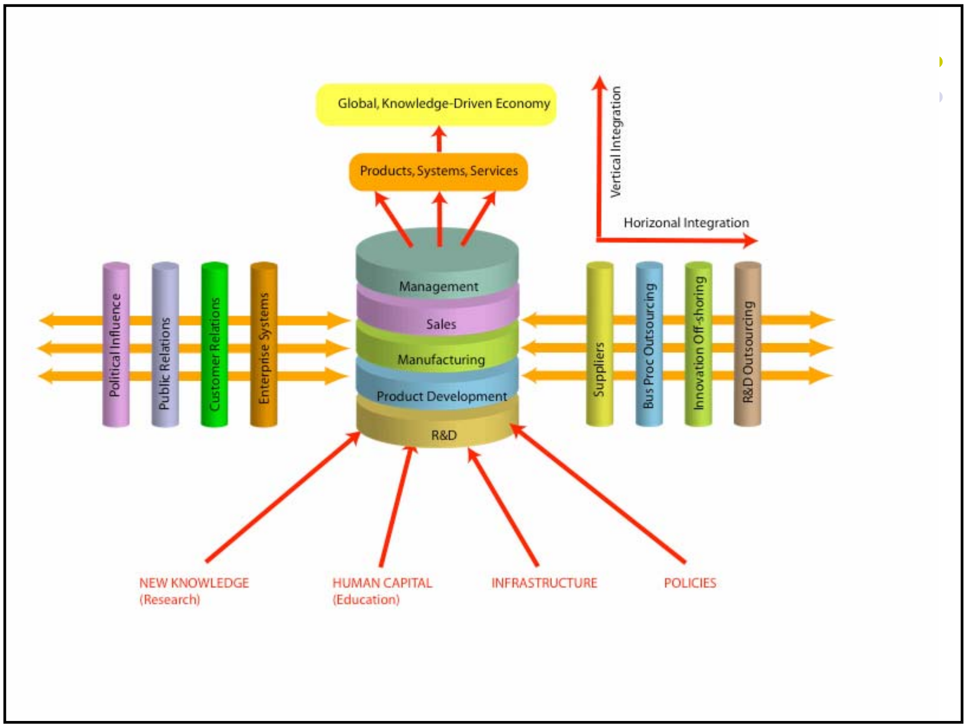

Global, Knowledge-Driven Economy
Products, Systems, Services
Vertical Integration
Horizonal Integration
Political Influence
Public Relations
Customer Relations
Enterprise Systems
Management
Sales
Manufacturing
Product Development
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(Research)
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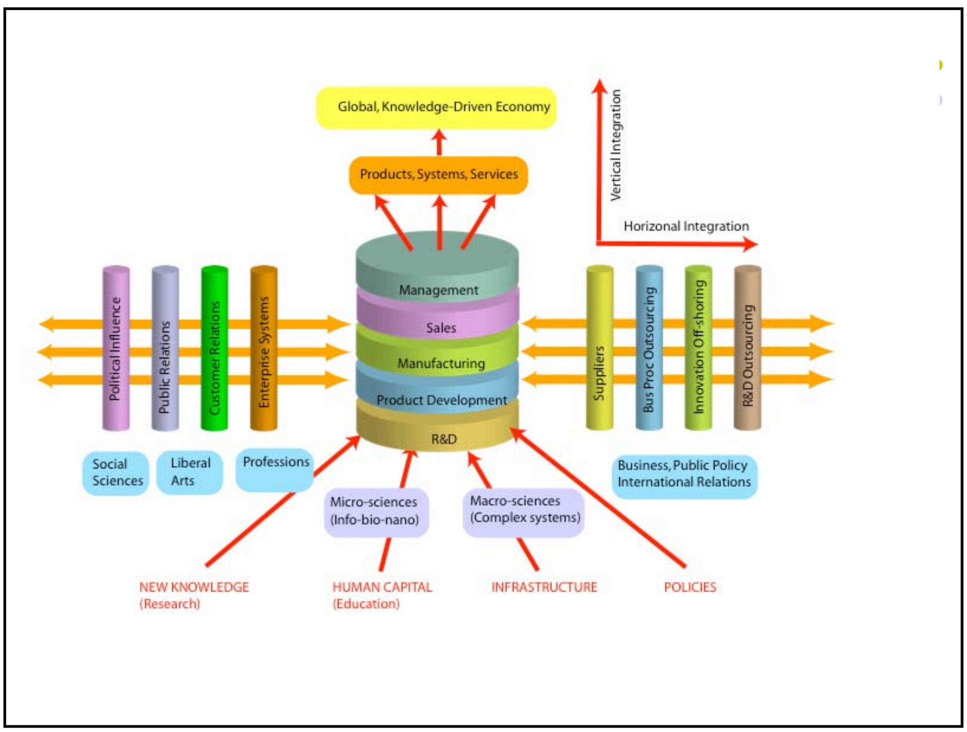

Global, Knowledge-Driven Economy
Products, Systems, Services
Vertical Integration
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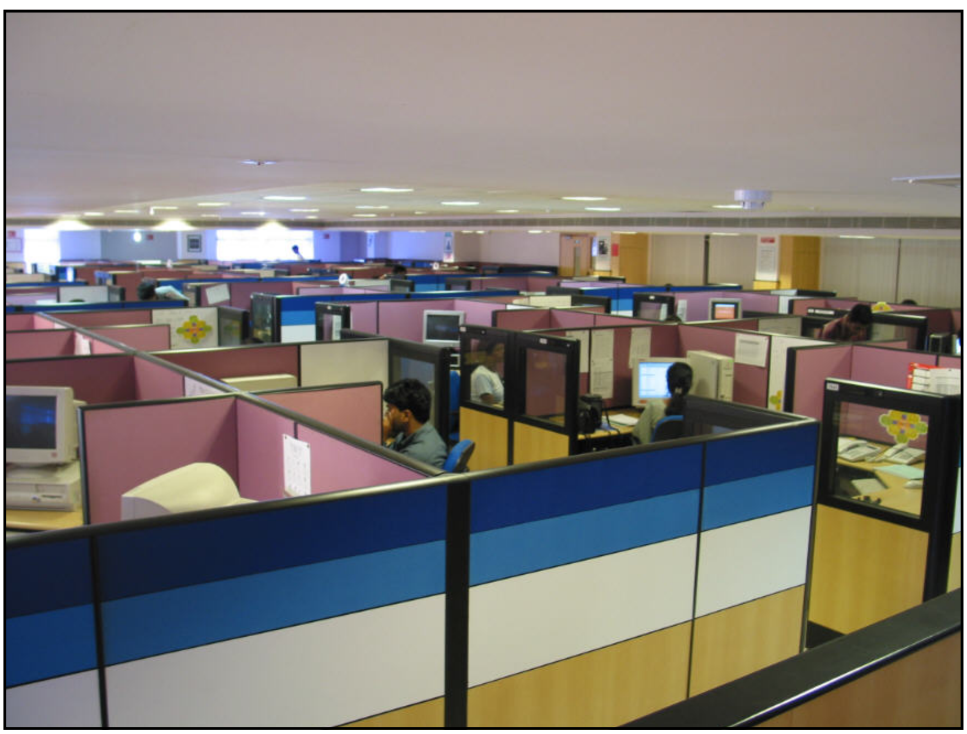
Public Relations
Customer Relations
Enterprise Systems
Management
Sales
Manufacturing
Product Development
R&D
Suppliers
Bus Proc Outsourcing
Innovation Off-shoring
R&D Outsourcing
Social Sciences
Liberal Arts
Professions
Micro-sciences (Info-bio-nano)
Macro-sciences (Complex systems)
Business, Public Policy International Relations
NEW KNOWLEDGE
(Research)
HUMAN CAPITAL
(Education)
INFRASTRUCTURE
POLICIES

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The Global Economy

- Today's global corporations manage their technology activities to take advantage of the most capable, creative, and cost-effective engineering talent, wherever they find it.
- The rapid evolution of high quality engineering services in developing economies with low labor costs raises a serious question about the viability of the U.S. engineer.
- This is a moving target as global sourcing moves up the value chain to product design, development, and innovation.

The Challenge to US Engineers

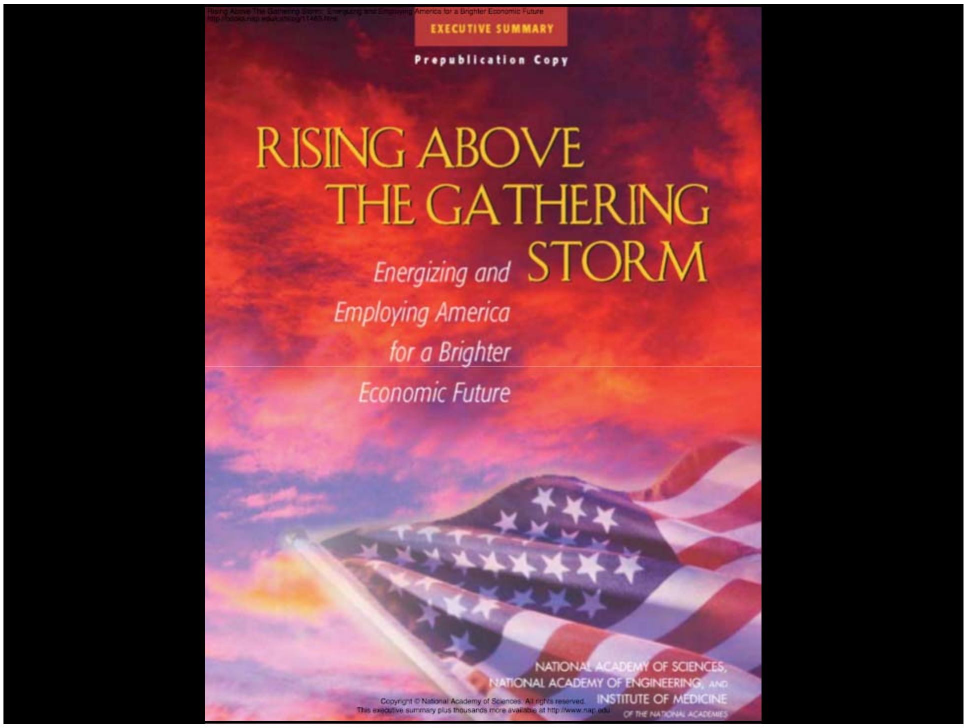
- Engineers must develop the capacity of working in global markets characterized by great cultural diversity.
- This requires a much faster pace of innovation, shorter product cycles, lower prices, and higher quality than ever before.
- Global innovation requires a shift from traditional problem solving and design skills to more innovative solutions imbedded in an array of social, environmental, cultural, and ethical issues.
- And they must achieve several times the value-added of engineers in other parts of the world to sustain their competitiveness relative to global sourcing.

Prestige and Influence?

- In the U.S. the engineering profession still tends to be held in relatively low public esteem compared to other learned professions such as law and medicine.
- American industry utilizes engineers as consumable commodities, subject to layoffs or off shoring when their skills become obsolete or replaceable by cheaper engineering services from abroad.
- Industry managers are limited in increasing head count of U.S. engineers relative to off shoring; many said they would not recommend engineering to their children.
- Students sense this, as evidenced by declining interest in engineering relative to business, law, and medicine.

The Gathering Storm

- "The U.S. is not graduating the volume of engineers and scientists, we do not have a lock on the infrastructure, and we are either flat-lining or cutting back our investments in physical science and engineering. The only crisis the U.S. thinks it is in today is the war on terrorism. It's not!" (Craig Barrett)
- "The U.S. has started to lose its worldwide dominance in critical areas of science and innovation. Europe and Asia are making large investments in physical science and engineering, while the U.S. has been obsessed with biomedical research to the neglect of other areas." (William Broad)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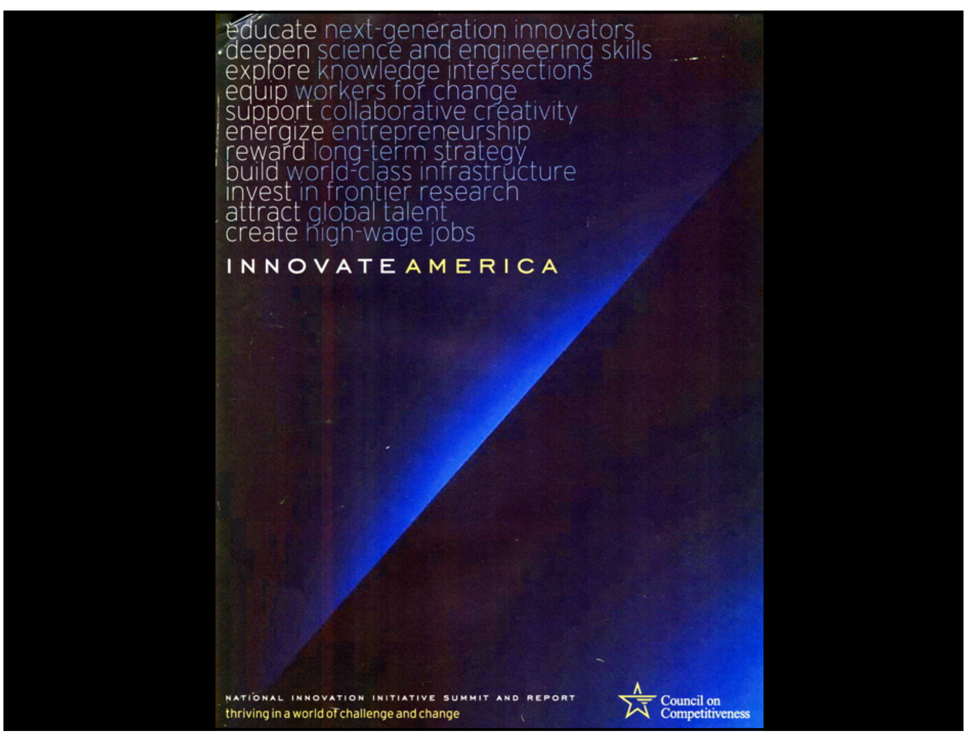
educate next-generation innovators
deepen science and engineering skills
explore knowledge intersections
equip workers for change
support collaborative creativity
energize entrepreneurship
reward long-term strategy
build world-class infrastructure
invest in frontier research
attract global talent
create high-wage jobs
INNOVATE AMERICA
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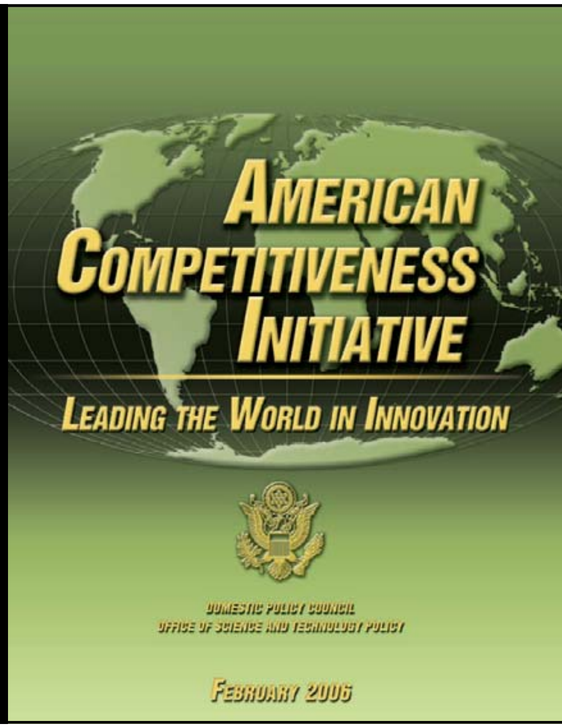
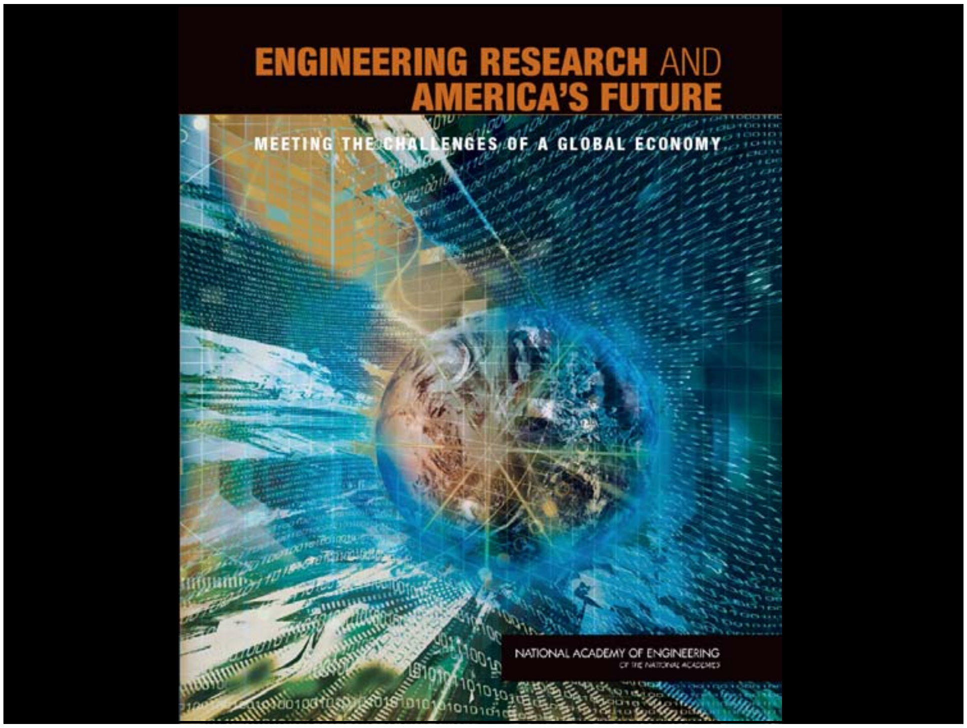
Council on Competitiveness



Engineering Research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MEETING THE CHALLENGES OF A GLOBAL ECONOMY
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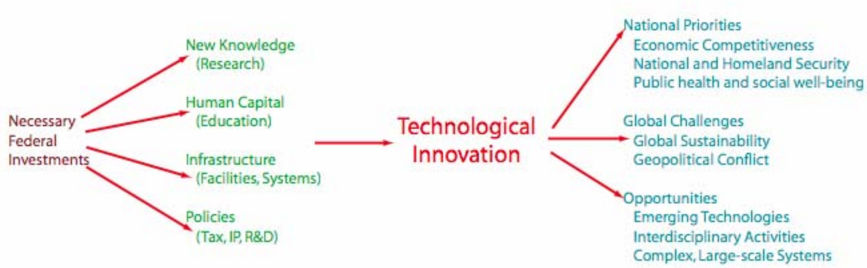
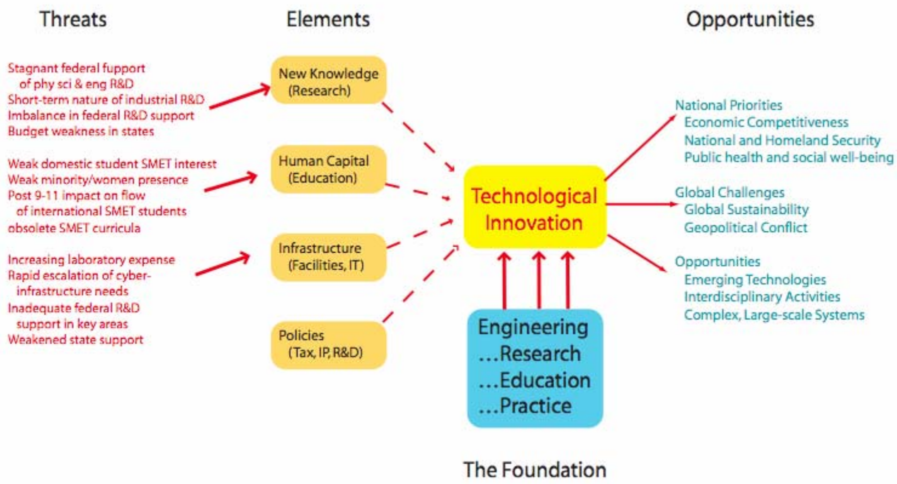
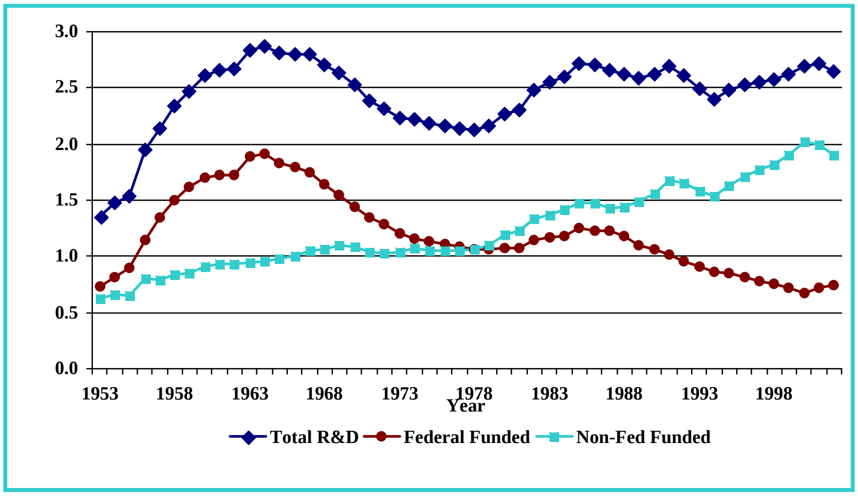

Necessary Federal Investments
New Knowledge (Research)
Human Capital (Education)
Infrastructure (Facilities, Systems)
Policies (Tax, IP, R&D)
Technological Innovation
National Priorities
Economic Competitiveness
National and Homeland Security
Public health and social well-being
Global Challenges
Global Sustainability
Geopolitical Conflict
Opportunities
Emerging Technologies
Interdisciplinary Activities
Complex, Large-scale Systems

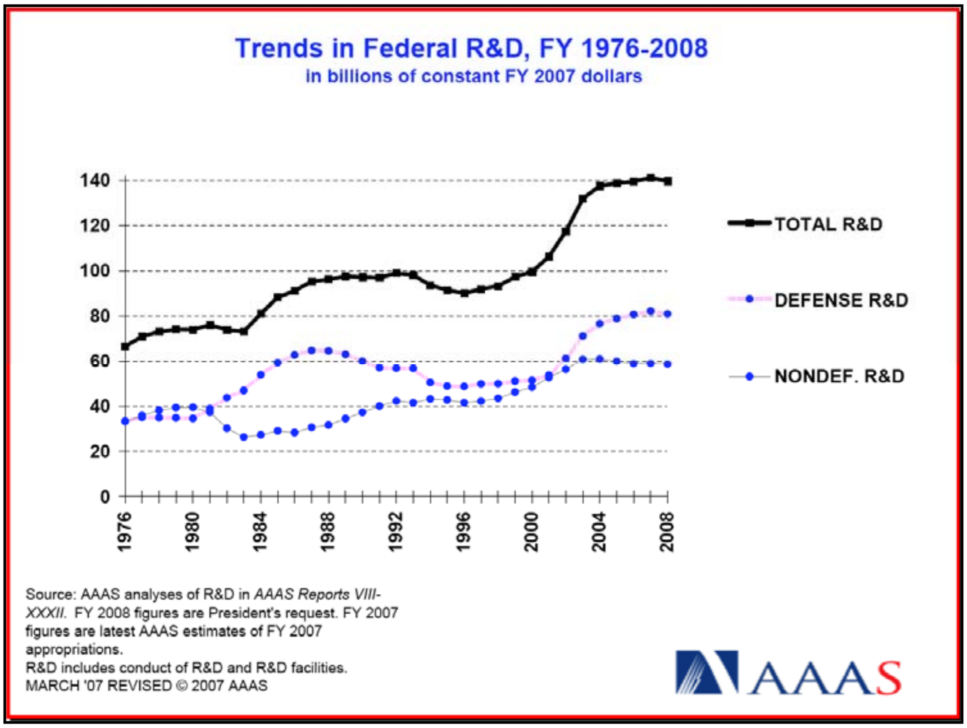


Disturbing Trends

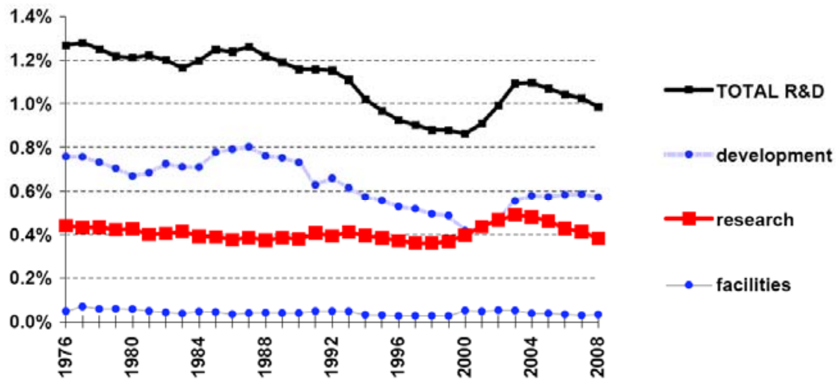
- Large and growing imbalance in federal R&D funding (e.g., NIH = $30 B, NSF = $6 B)
- Federal R&D has declined from 70% of national R&D in 1970s to less than 30% today.
- Increased emphasis on short-term R&D in industry and government-funded R&D
- Deterioration of engineering research infrastructure
- Declining interest of U.S. students in STEM careers
- Eroding ability of U.S. to attract STEM students, scientists, and engineers from abroad.

Federal vs. Nonfederal R&D as Percent of GDP





Trends in Federal R&D as % of GDP, FY 1976-2008

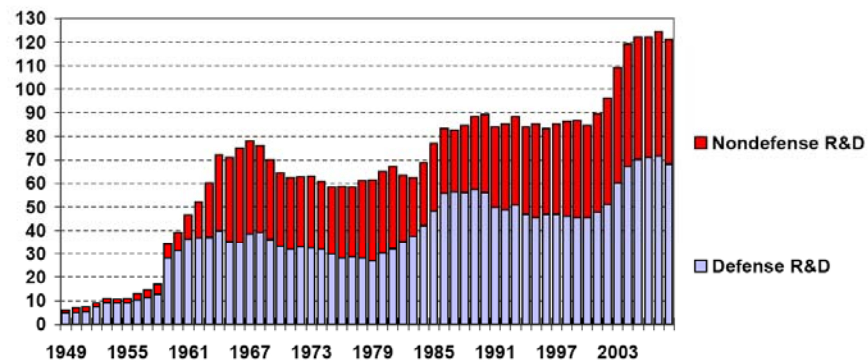


Source: AAAS analyses of R&D in annual AAAS R&D reports. FY 2008 figures are President's request. R&D includes conduct of R&D and R&D facilities. Data to 1984 are obligations from the NSF Federal Funds survey. GDP figures are from OMB, Budget of the U.S. Government FY 2008.

AAAS

Federal Spending on Defense and Nondefense R&D

Outlays for the conduct of R&D, FY 1949-2008, billions of constant FY 2007 dollars

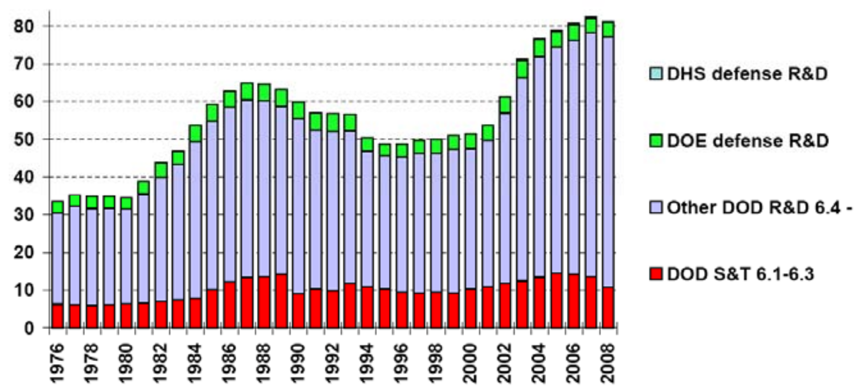


Source: AAAS, based on OMB Historical Tables in *Budget of the United States Government FY 2008*. Constant dollar conversions based on GDP deflators. FY 2008 is the President's request.
Note: Some Energy programs shifted to General Science beginning in FY 1998.

AAAS

Trends in Defense R&D, FY 1976-2008 *

in billions of constant FY 2007 dollars

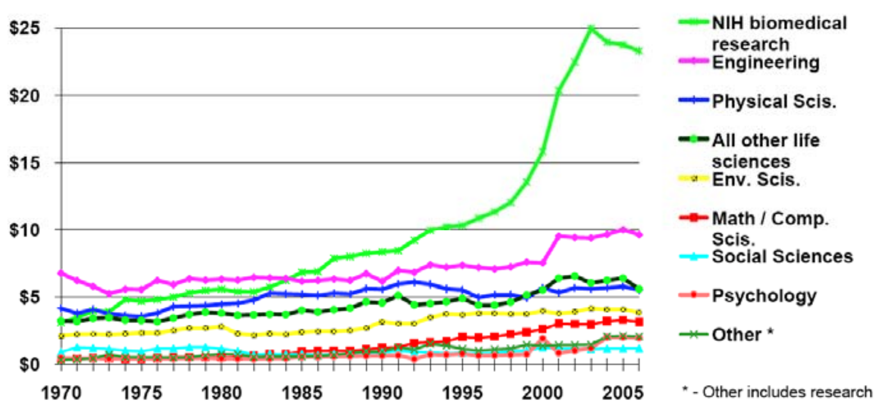


Source: AAAS analyses of R&D in *AAAS Reports VIII- XXXII.* * - FY 2008 figures are President's request. 2007 and 2008 figures include requested supplementals. R&D includes conduct of R&D and R&D facilities. DOD S&T figures are not strictly comparable for all years because of changing definitions.

AAAS

Trends in Federal Research by Discipline, FY 1970-2006

obligations in billions of constant FY 2007 dollars



* - Other includes research not classified (includes basic research and applied research; excludes development and R&D facilities)

Life sciences - split into NIH support for biomedical research and all other agencies' support for life sciences.
Source: National Science Foundation, *Federal Funds for Research and Development FY 2004, 2005 , 2006,* 2006. FY 2005 and 2006 data are preliminary. Constant-dollar conversions based on OMB's GDP deflators.

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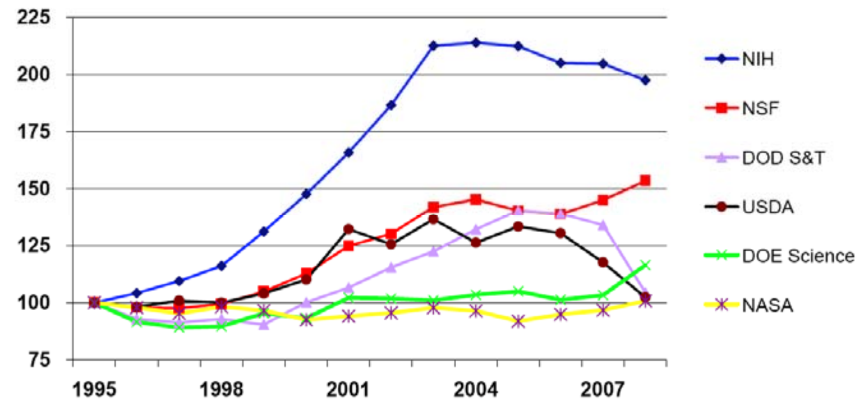
Trends in Federal R&D, FY 1995-2008*

selected agencies in constant dollars, FY 1995=100



Source: AAAS analyses of R&D in *AAAS Reports VIII- XXXII.*
* FY 2008 figures are President's request. FY 2007 figures are latest AAAS estimates of FY 2007 appropriations.
R&D includes conduct of R&D and R&D facilities.
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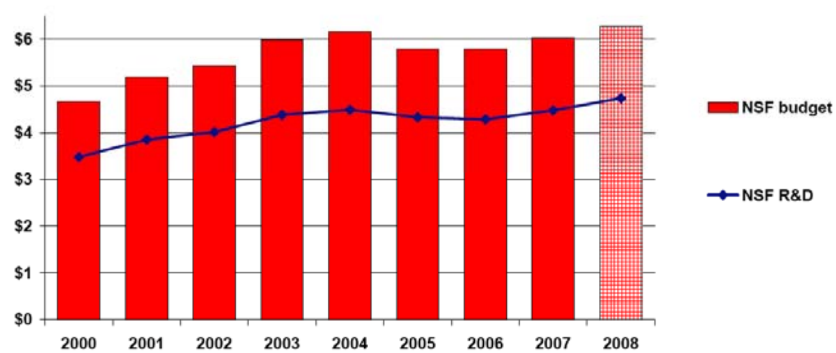
AAAS

National Science Foundation Budget, FY 2000-2008

(budget authority in billions of constant FY 2007 dollars)



Source: National Science Foundation, and latest AAAS estimates of FY 2008 budget. FY 2008 is budget request; FY 2007 is estimate of final appropriation.
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AAAS

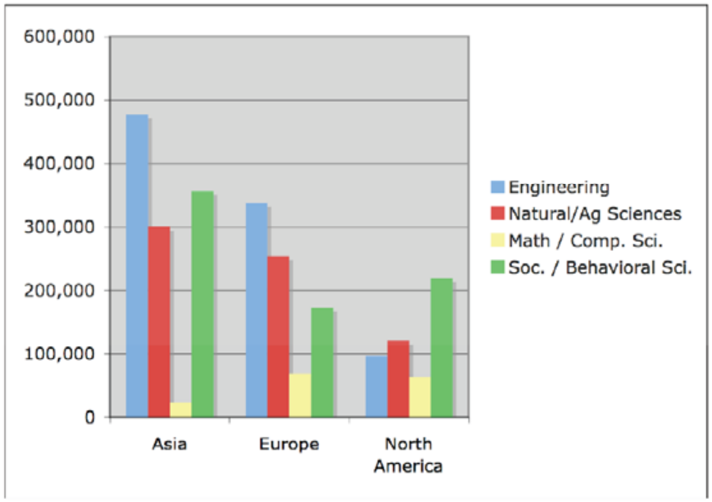
Engineering Education

Engineering Workforce Concerns

- Student interest in science and engineering careers is at a low ebb–and likely to go much lower as the implications of global sourcing become more apparent!
- Cumbersome immigration policies in the wake of 9-11 along with negative international reaction to U.S. foreign policy is threatening the pipeline of talented foreign science and engineering students.
- It is increasingly clear that a far bolder and more effective strategy is necessary if we are to tap the talents of all segments of our increasingly diverse society (particularly women and underrepresented minorities).

First University S&E Degrees

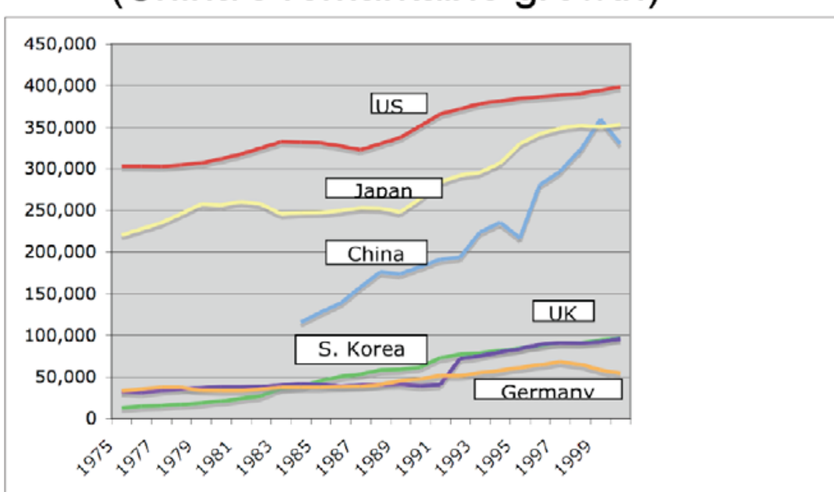
(Asia dominates.)



Source: Science and Engineering Indicators 2004, National Science Foundation, Washington, DC

S&E First University Degrees

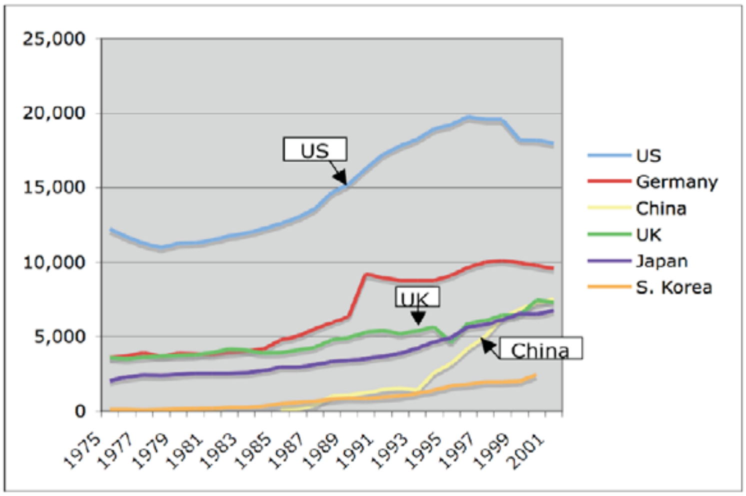
(China's remarkable growth)



Source: Science and Engineering Indicators 2004, National Science Foundation, Washington, DC

S&E Doctoral Degrees

(Similar trends with a 10 year lag; US slows.)



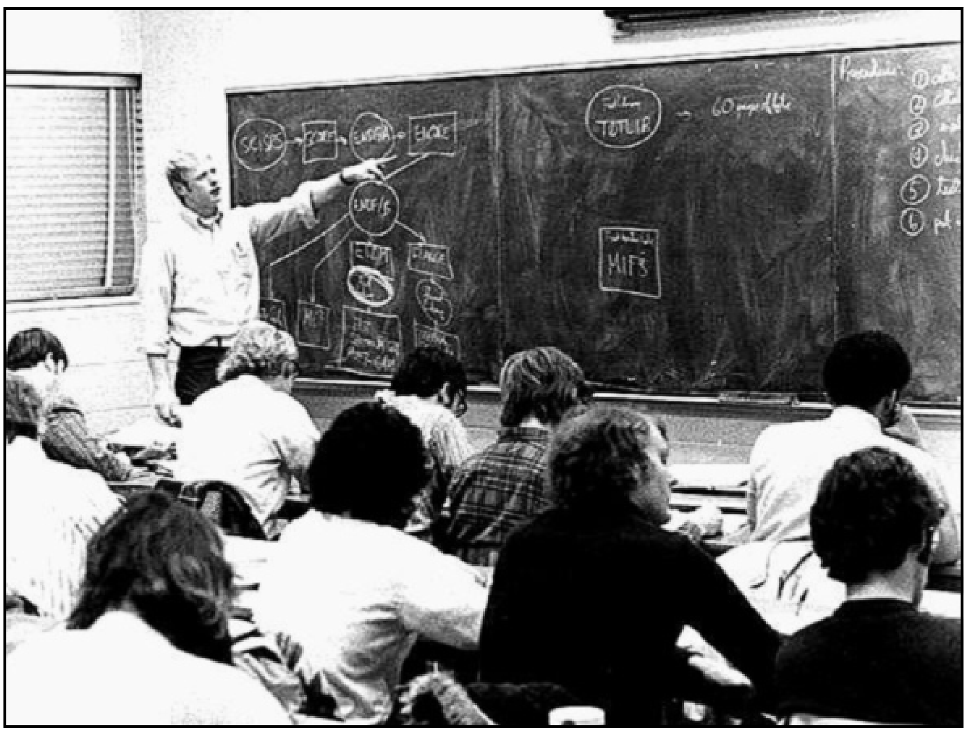
Source: Science and Engineering Indicators 2004, National Science Foundation, Washington, DC

International Comparisons

- While absolute comparison production of U.S. engineers (85,000/y) with China (350,000/y) and India (170,000/y), of far more importance is the trend.
- Similarly, PhD comparisons of U.S. (17,000/y) and China (8,000/y) is misleading; China is doubling every 5 years.
- Today the U.S. currently produces less than 8% of world's engineers and this is dropping fast.
- Clearly the U.S. cannot achieve engineering leadership through the number of engineering graduates. It must focus instead on quality and value-added through new educational paradigms for a rapidly changing, global, knowledge-driven economy.

Yet, same old…same old…

- Curriculum still stresses analytical skills to solve well-defined problems rather than engineering design, innovation, and systems integration.
- Continue to pretend that an undergraduate education is sufficient, despite fact that curriculum has become bloated and overloaded, pushing aside liberal education.
- Failed to take a more formal approach to lifelong learning like other professions (medicine, law).
- Need to broaden education to include topics such as innovation, entrepreneurial skills, globalization, knowledge integration.
- And make it all exciting and attractive to young people!



Transforming Engineering Education

"For too long traditional engineering education has been characterize by narrow, discipline-specific approaches and methods, an inflexible curriculum focused exclusively on educating engineers (as opposed to all students), an emphasis on individual effort rather than team projects, and little appreciation for technology's societal context. Engineering education has not generally emphasized communication and leadership skills, often hampering engineers' effectiveness in applying solutions. Engineering is perceived by the larger community to be specialized and inaccessible, and engineers are often seen as a largely homogenous group, set apart from their classmates in the humanities, social sciences, and natural sciences. Given these perceptions, few women and minorities participate in engineering, and non-engineering students are rarely drawn to engineering courses." Princeton, 2005

We need new paradigms…

- To respond to incredible pace of intellectual change (e.g., from reductionism to complexity, analysis to synthesis, disciplinary to multidisciplinary)
- To accommodate a far more holistic approach to addressing social needs and priorities, linking economic, environmental, legal, and political considerations with technological design and innovation.
- To reflect in diversity, quality, and rigor the characteristics necessary to serve a 21st C world.
- To infuse in our students a new spirit of adventure, in which risk-taking and innovation are seen as an integral part of engineering practice.

THE OLIN "EDUCATIONAL SYSTEM"
Applicants who are:
Extensive Admission Screening
Educational Program and Personal Development
Engineering Project Experience
start

A Roadmap to 21st Century Engineering

Conclusion 1

In a global, knowledge-driven economy, technological innovation—the transformation of knowledge into products, processes, and services—is critical to competitiveness, long-term productivity growth, and the generation of wealth. Preeminence in technological innovation requires leadership in all aspects of engineering: engineering research to bridge scientific discovery and practical applications; engineering education to give engineers and technologists the skills to create and exploit knowledge and technological innovation; and the engineering profession and practice to translate knowledge into innovative, competitive products and services.

Conclusion 2

To compete with talented engineers in other nations in far greater numbers and with far lower wage structures, American engineers must be able to add significantly more value than their counterparts abroad through their greater intellectual span, their capacity to innovate, their entrepreneurial zeal, and their ability to address the grand challenges facing our world.

Conclusion 3

It is similarly essential to elevate the status of the engineering profession, providing it with the prestige and influence to play the role it must in an increasingly technology-driven world while creating sufficiently flexible and satisfying career paths to attract outstanding students.

Conclusion 4

From this perspective the key to producing such world-class engineers is to take advantage of the fact that universities in the United States are more comprehensive and hence capable of providing broader educations, provided engineering schools, accreditation agencies such as ABET, and the marketplace is willing to embrace such an objective. Essentially all other learned professions have long ago moved in this direction (law, medicine, business, architecture), requiring a broad liberal arts baccalaureate education as a prerequisite for professional education at the graduate level.

Engineering Practice

Goal: To establish engineering practice as a true learned profession, similar in rigor, intellectual breadth, stature, and influence to law and medicine, with extensive post-graduate education and a culture more characteristic of professional guilds than corporate employees.

Proposed Action

Proposed Action: Engineering professional and disciplinary societies, working with engineering leadership groups such as the NAE, ABET, and AAEE, should strive to create a guild culture in the engineering professional similar to those characterizing other learned professions such as medicine and law.

In such a guild culture engineers would identify more with their profession than their employer, taking pride in being a part of a true profession whose services are highly valued by cliends and society.

A Guild Culture

Note the transition:

Engineers: from employees to professionals

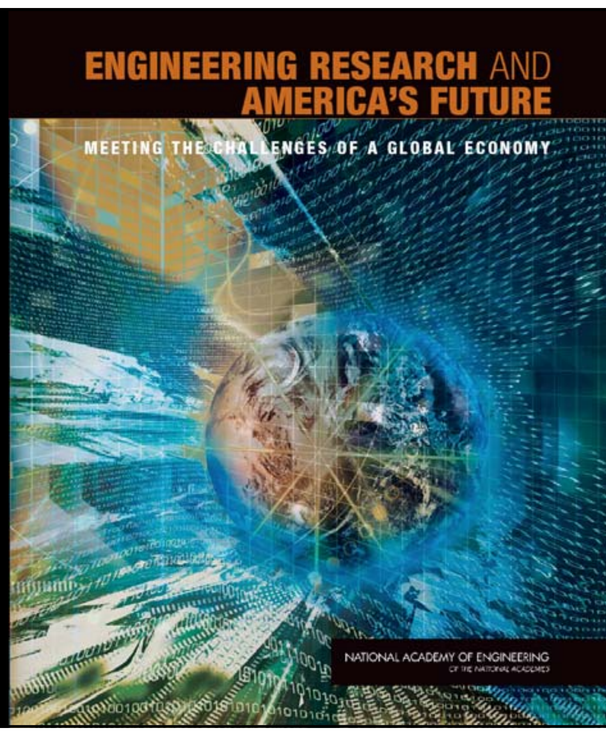
Market: from employers to clients or customers

Society: from occupation to profession

The Challenge: The great diversity among engineering professional and disciplinary societies and engineering roles that inhibits working together to develop sufficient influence at the state and federal level to elevate the status of the profession.

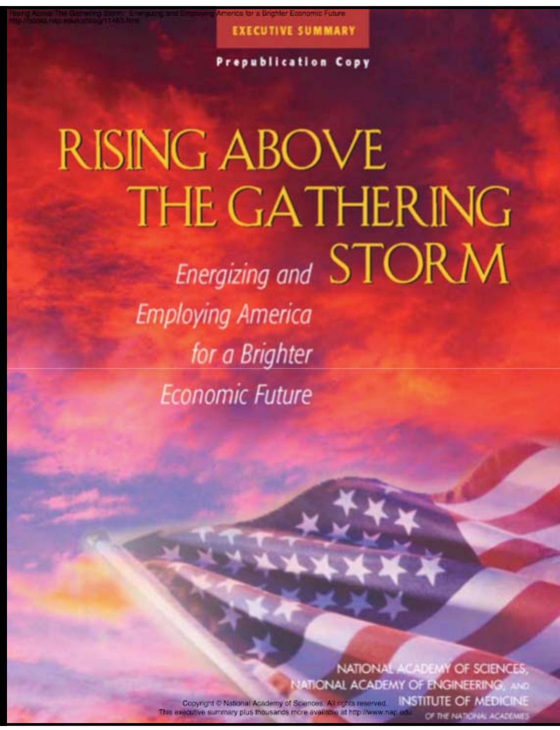
Engineering Research

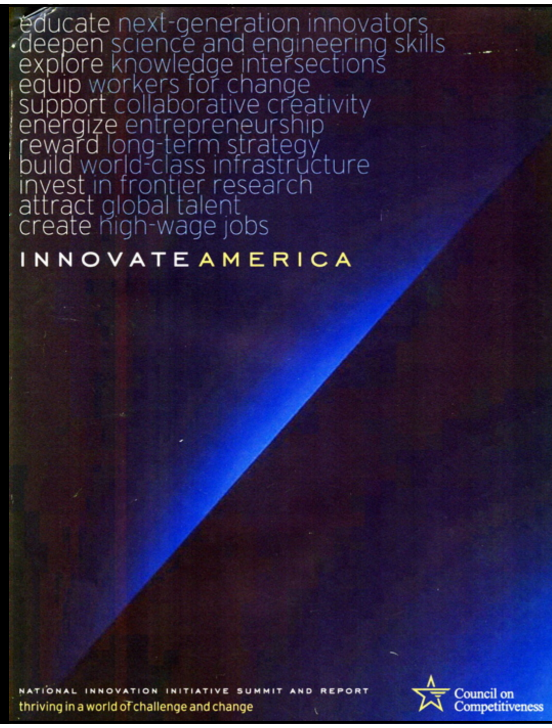
Goal: To redefine the nature of basic and applied engineering research, developing new research paradigms that better address compelling social priorities than those characterizing scientific research.

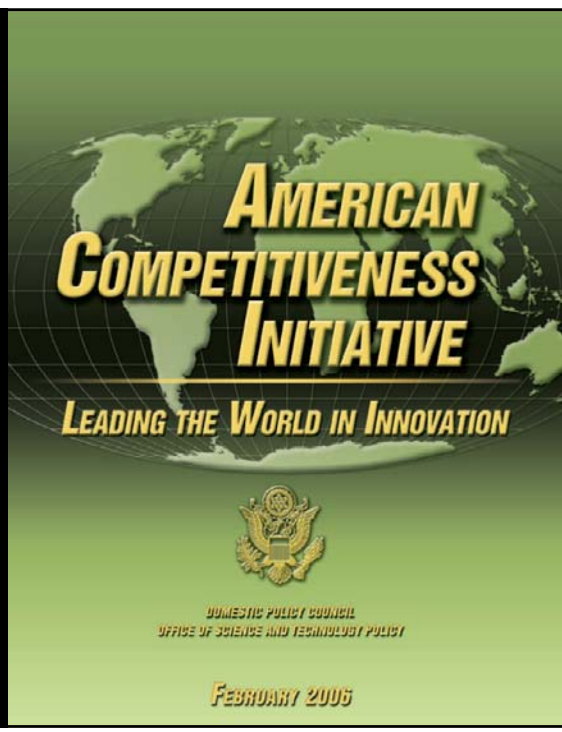


Recommendations

- Balancing Federal R&D Portfolio
- Re-establishing Basic Engineering Research As A Priority of Industry
- Strengthening Linkages Between Industry and Research Universities
- Human Capital
- Discovery-Innovation Institutes




educate next-generation innovators
deepen science and engineering skills
explore knowledge intersections
equip workers for change
support collaborative creativity
energize entrepreneurship
reward long-term strategy
build world-class infrastructure
invest in frontier research
attract global talent
create high-wage jobs
INNOVATE AMERICA
NATIONAL INNOVATION INITIATIVE SUMMIT AND REPORT
thriving in a world of challenge and change
Council on Competitiveness


AMERICAN COMPETITIVENESS INITIATIVE
LEADING THE WORLD IN INNOVATION
DOMESTIC POLICY COUNCIL
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
FEBRUARY 2006

The American Competitiveness Initiative

- Double federal investment in basic research in physical science and engineering (from $9.75 B/y to $19.45 B/y) over next 10 years, focused on NSF, DOE-OS, NIST.
- Major investment in STEM education
- Tax policies designed to stimulate private sector R&D
- Streamlining intellectual property policies
- Immigration policies that attract the best and brightest scientific minds from around the world
- Building a business environment that stimulates and encourages entrepreneurship through free and flexible labor, capital, and product markets that rapidly diffuse new productive technologies.

Recommendations

- Balancing Federal R&D Portfolio
- Re-establishing Basic Engineering Research As A Priority of Industry
- Strengthening Linkages Between Industry and Research Universities
- Human Capital
- Discovery-Innovation Institutes

Proposed Action

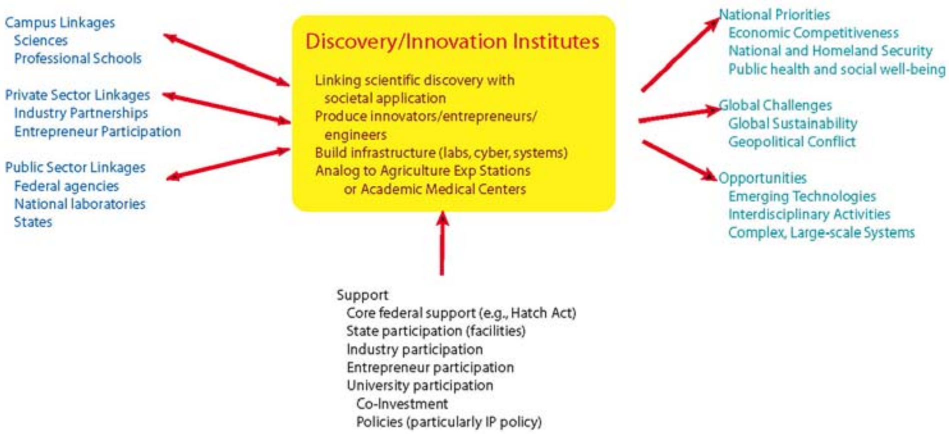
The federal government, in close collaboration with industry, should launch a large number of *Discovery Innovation Institutes* at American universities with the mission of linking fundamental scientific discoveries with technological innovations to build the knowledge base essential for new products, processes, and services to meet the needs of society.

U.S. Leadership in Innovation will Require Changes

- In the way research is prioritized, funded, and conducted.
- In the education of engineers and scientists.
- In policies and legal structures such as intellectual property.
- In strategies to maximize contributions from institutions (universities, CR&D, federal agencies, national laboratories)

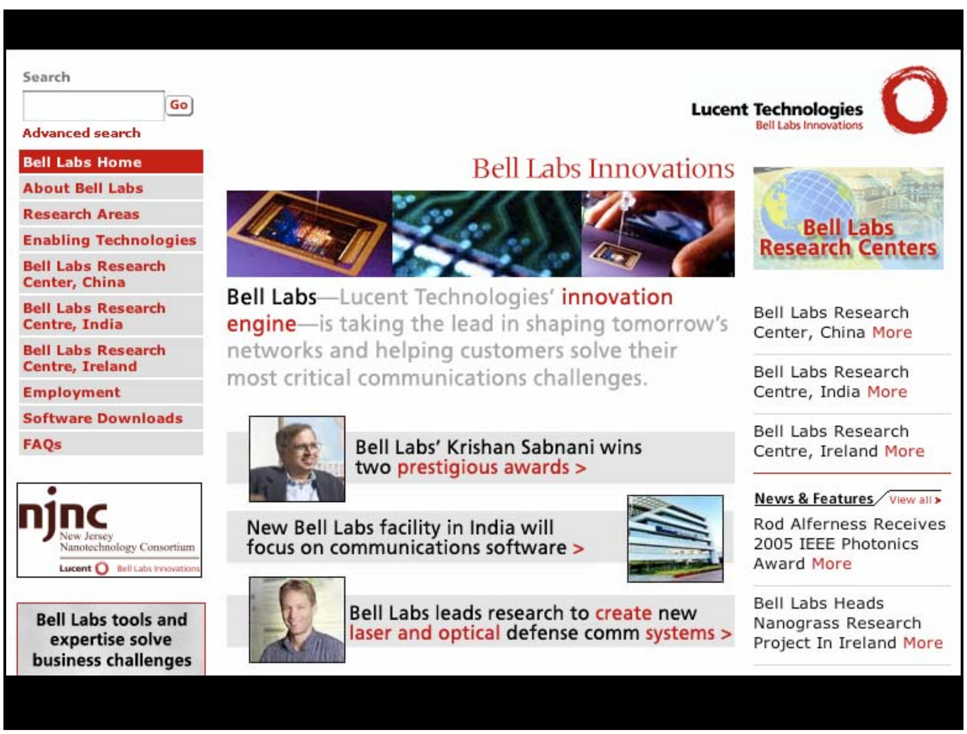
Discovery Innovation Institutes

To address the challenge of maintaining the nation's leadership in technological innovation, the committee is convinced that a bold, transformative initiative is required. To this end, we recommend the establishment of multidisciplinary Discovery-Innovation Institutes on university campuses designed to perform the engineering research that links fundamental scientific discovery with the technological innovation to create the products, processes, and services needed by society.



Discovery-Innovation Institutes

- Like agricultural experiment stations, they would be responsive to societal priorities.
- Like academic medical centers they would bring together research, education, and practice.
- Like CR&D laboratories, they would link fundamental discoveries with the engineering research necessary to yield innovative products, services, and systems, but while also educating the next generation technical workforce.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Discovery-Innovation Institutes

- Although primarily associated with engineering schools, DIIs would partner with other professional schools (e.g., business, medicine, law) and academic disciplines.
- To ensure the necessary transformative impact, the DII program should be funded at levels comparable to other major federal initiatives such as biomedicine and manned spaceflight, e.g., building to several billion dollars per year and distributed broadly through an interagency competitive grants program.

In summary

- DIIs would be engines of innovation that would transform institutions, policy, and culture and enable our nation to solve critical problems and maintain leadership in a global, knowledge-driven society.
- The DII proposal is designed to illustrate the bold character and significant funding level we believe are necessary to secure the nation's leadership in technological innovation.

Engineering Education

Goal 1: To adopt a systemic approach to the reform of engineering education, recognizing the importance of diverse approaches–albeit characterized by quality and rigor–to serve the highly diverse technology needs of our society.

Goal 2: To establish engineering as a true liberal arts discipline, similar to the natural science, social sciences, and humanities by imbedding it in the general education requirements of a college graduate for an increasingly technology-driven and dependent society of the century ahead.

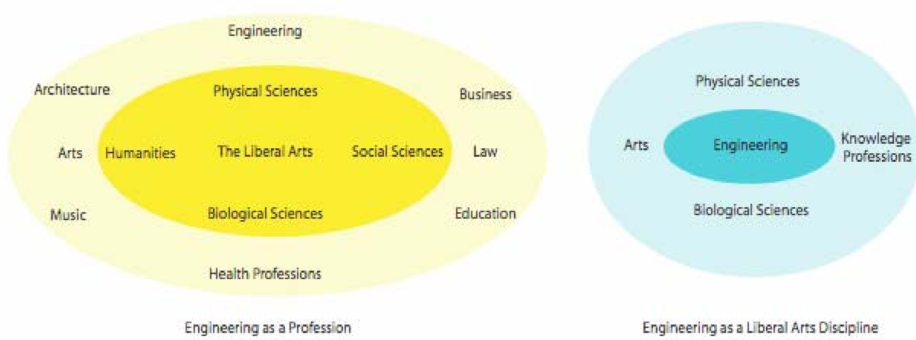
Goal 3: To achieve far greater diversity among the participants in engineering, the roles and types of engineers needed by our nation, and the programs engaged in preparing them for professional practice.

A Significant U.S. Advantage

- The comprehensive nature of universities in which most engineering education occurs, spanning the range of academic disciplines and professions, from liberal arts to law, medicine, and other learned professions.
- American universities have the capacity to augment STEM education with the broader exposure to humanities, arts, and social sciences, critical to building both the creative skills and cultural awareness necessary to compete in a globally integrated society.
- Their integration of education, research, and service provides a formidable environment for educating 21st century engineers.

A new paradigm

- U.S. universities have the unique capacity to develop a new paradigm for engineering education that takes full advantage of their comprehensive nature to create a new breed of engineer, capability of adding much higher value in a global, knowledge economy.
- But this will require a separation of engineering as an academic discipline from engineering as a learned profession!



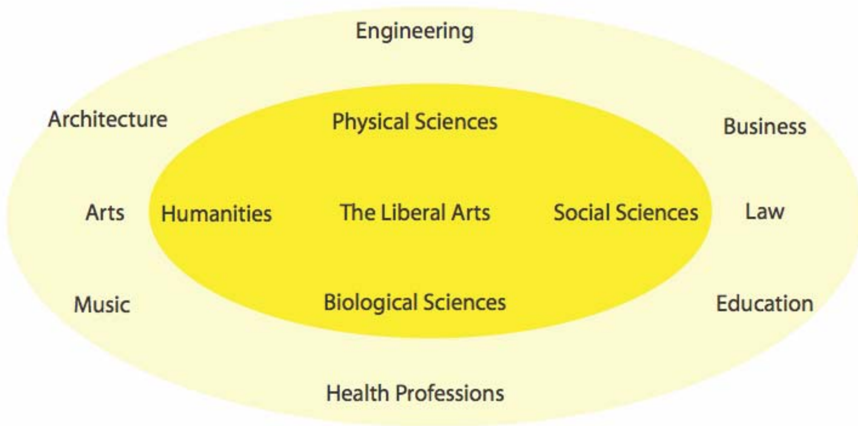
Proposed Actions

Action 1: Working closely with industry and professional societies, higher education should establish *graduate professional schools of engineering* that would offer practice-based degrees at the post-baccalaureate level as the entry degree into the engineering profession.

The most effective way to raise the value, prestige, and influence of the engineering profession is to create true post-baccalaureate professional schools, with practice-experienced faculty, which provide clinical practice experience for students, similar to medicine and law.

Professional Schools

- Shifting the professional education and training of engineers to two- or three-year practice-focused degree programs.
- Staffed by faculty with strong backgrounds in practice and scholarly interests in areas such as design, innovation, entrepreneurial activities, and global systems.
- Students drawn from an array of STEM undergraduate programs.
- Augmented by either internships or affiliated organizations (e.g., discovery-innovation institutes, engineering services companies)



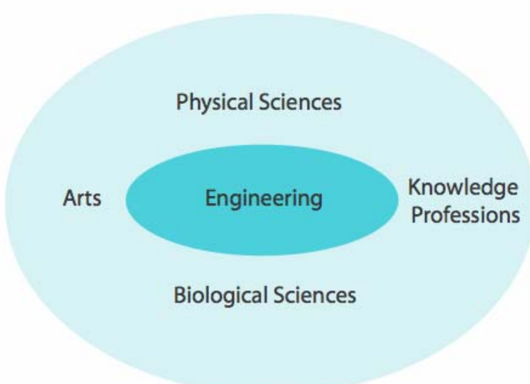
Engineering as a Profession

Proposed Actions (cont.)

Action 2: *Undergraduate engineering* should be reconfigured as an *academic discipline*, *similar to other liberal arts disciplines* in the sciences, arts, and humanities, thereby providing students with more flexibility to benefit from the broader educational opportunities offered by the comprehensive American university with the goal of preparing them for a lifetime of further learning rather than professional practice.

Opportunities

- Removing burdens of professional accreditation would allow UG engineering to be reconfigured as other academic disciplines, thereby providing students with more flexibility to benefit from the broader educational opportunities offered by the comprehensive university.
- This would reverse the trend toward ever more narrow specialization among engineering majors currently driven by the reductionist approach of science rather than the highly integrative character of engineering synthesis.
- Reframing UG engineering as an academic discipline rather than a pre-professional program would allow students to benefit from a truly liberal education.



Engineering as a Liberal Arts Discipline

Proposed Action (cont.)

Action 3: The academic discipline of engineering (or, perhaps more broadly technology) should be *included in the liberal arts canon* undergirding a 21st undergraduate education for all students.

In a world increasingly dependent upon technology, it seems appropriate that the engineering discipline be added to the liberal arts core of a general education, much as the natural sciences were added a century ago to the classical liberal arts (the *trivium* and *quadrivium*)

Liberal arts for the 21st C

- Recall the liberals arts are an ancient concept that earns studies intended to provide general knowledge and intellectual skills rather than occupational or professional skills.
- In proposing that engineering be added to the liberal arts we are not referring to the foundation of science, mathematics, and engineering science but rather those unique concepts one must master to understand technology such as synthesis and design, innovation and entrepreneurial activities, technology development and management, benefit-risk analysis, and knowledge integration across horizontal and vertical intellectual spans.

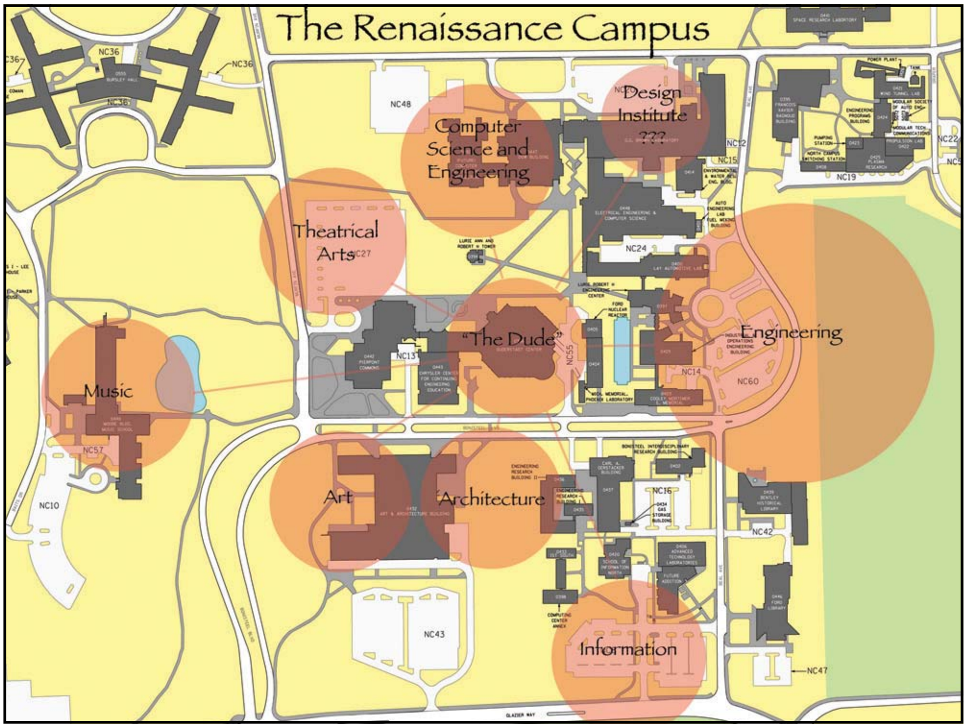
The Future of Engineering Schools

- What would the separation of engineering as a profession and a discipline portend for existing engineering schools?
- Would they evolve into science-like disciplines with extensive service teaching obligations?
- Where would professional engineering schools (and faculties) reside in the university?

	Education	*Research*	*Organizations*
Academic Medical Center	Biomedical Sciences Physician Training Residencies	Basic Research Clinical Research Clinical Trials	Teaching Hospitals Research Centers
	Degrees …M.D., Ph.D.	Publications Patents	Clinical Care Spinoff Companies

Academic Medical Center	*Education*	*Research*	*Organizations*
	Biomedical Sciences Physician Training Residencies	Basic Research Clinical Research Clinical Trials	Teaching Hospitals Research Centers
	Degrees ...M.D., Ph.D.	Publications Patents	Clinical Care Spinoff Companies

Engineering School	*Education*	*Research*	*Organizations*
	Undergraduate Graduate Professional	Basic Research Applied Research Systems Development	Discovery-Innovation Centers Captive Consulting Companies Practice Schools
	Degrees ...B.S., B.A. ...M.S., Ph.D. ...M.Eng., D. Eng..	Publications Patents Systems, Products	Engineering Services Systems, Products Spinoff Companies



Wm Wulf, NAE President

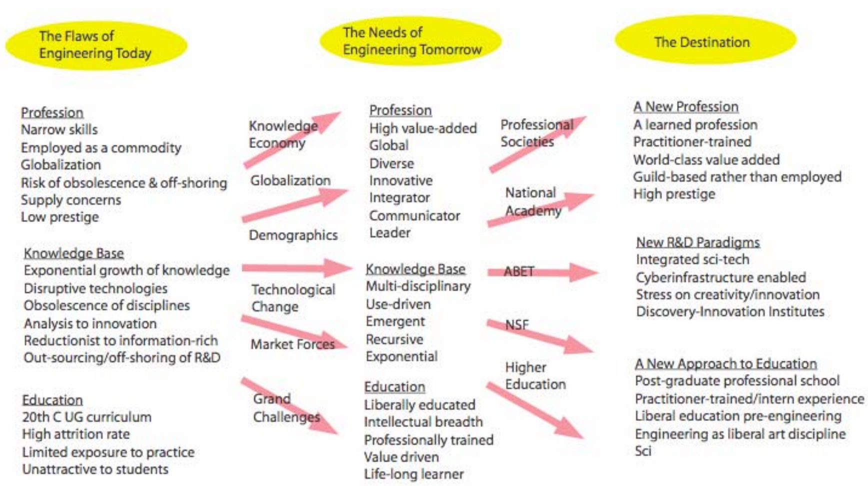
In his 2003 address to the National Academy, Bill Wulf pleaded: "We have studied engineering reform to death. While there are differences among the reports, the differences are not great. Let's get on with it! It is urgent that we do!"

He then went on to observe: "I honestly don't know the answer, but I have a hypothesis–namely, that most do not believe change is necessary. They are following the time-tested adage---"if it ain't broke, don't fix it."

JJD's View

"Well, American engineering IS broke, at least when measured against the emerging technology capabilities of the rest of the world. Otherwise it would not be outsourced and off-shored! We can no longer afford simply chipping away at the edges of fundamental transformation of the engineering profession and its preparation."

"Radical transformation will require radical actions!"



What's Next?

- Option 1: Benign Neglect: Simply continue the status quo, accepting the current global market realities, and reacting as best one can to new requirements such as the need for global engineers…and wait until conditions deteriorate sufficiently to stimulate bolder action.
- Option 2: Evolution (Education and Persuasion): Launch a major outreach and education campaign aimed at industry, government and the public of the importance of sustaining and enhancing domestic engineering capacity through additional investments in engineering education and research to raise the value-added of American engineers.

What's Next? (cont.)

- Option 3: Revolution (Politics and Cartels): Engineering professional societies would emulate the efforts of the medical and law professions to seek legislation at the state and federal level to create a regulatory environment sufficient to empower the engineering profession.
- Option 4: Punctuated Evolution and Spontaneous Emergence: Search for tipping points that would drive rapid and fundamental change in engineering practice, research, and education (e.g., cyberinfrastructure, open education resources, new business paradigms).

Take Heart…

“Perhaps the sentiments contained in the following pages, are not sufficiently fashionable to procure them general favour; a long habit of not thinking a thing wrong, gives it a superficial appearance of being right, and raises at first a formidable outcry in defense of custom. But the tumult soon subsides. Time makes more converts than reason.” (Paine, *Common Sense*, 1776)