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 outsourcing and offshoring, 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.
ME 100
California Institute of Technology
The Mechanical Engineering Centennial Celebration
It’s all about ME
1907 – 2007
March 30 & 31, 2007
An Interesting Comparison:

**Medicine**

...at the turn of the last century
Dr. Howard’s Office

Alonson Howard attended two medical schools – including the one at the University of Michigan – but did not graduate from either school. He simply returned home and became a doctor.

Doctors’ offices of the mid-1800s were very different from those today.

Alonson Howard ran this office around the time of the Civil War. He often made house calls to rural Michigan towns, traveling by horse or train. Many times he stayed overnight at patients’ homes to watch them. He made his own syrups and pills from herbs, roots and barks.

Built about 1840 in Tekonsha, Michigan.
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 (1916)
(Reproduced in 1960)
(Reproduced in 1979)

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 University 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
- 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!!!
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

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES
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
STEM Education Reports
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
THE ENGINEER OF 2020

VISIONS OF ENGINEERING IN THE NEW CENTURY

NATIONAL ACADEMY OF ENGINEERING OF THE NATIONAL ACADEMIES
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Lisa R. Lattuca, Patrick T. Terenzini, J. Fredericks Volkwein, and George D. Peterson

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Theodore C. Kennedy

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Jacquelyn F. Sullivan

Preparing Engineering Faculty as Educators
Susan A. Ambrose and Marie Norman

Redefining Engineering Disciplines for the Twenty-First Century
Zehev Tadmor

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Jennifer Turner, Cynthia J. Atman, Robin S. Adams, and Theresa Barker

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L. Dee Pink, Susan Ambrose, and Daniel Wheeler

Centered on Education Research
Diane T. Rover

January 2005 | Vol. 94 No. 1
In Search of Global Engineering Excellence

Educating the Next Generation of Engineers for the Global Workplace
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Report of the National Science Foundation Advisory Panel on Cyberinfrastructure

February 3, 2003
PREPARING FOR THE REVOLUTION

Information Technology and the Future of the Research University

NATIONAL RESEARCH COUNCIL
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Lessons from Corporations
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Engineering Today... and Tomorrow
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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.”
Global, Knowledge-Driven Economy

Products, Systems, Services

Management
Sales
Manufacturing
Product Development
R&D

NEW KNOWLEDGE (Research)
HUMAN CAPITAL (Education)
INFRASTRUCTURE
POLICIES

Political Influence
Public Relations
Customer Relations
Enterprise Systems

Suppliers
Bus Proc Outsourcing
Innovation Off-shoring
R&D Outsourcing
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.
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)
educate next-generation innovators
depth 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

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thriving in a world of challenge and change
Engineering Research
ENGINEERING RESEARCH AND AMERICA’S FUTURE

MEETING THE CHALLENGES OF A GLOBAL ECONOMY

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES
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, 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. 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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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. MARCH '07 REVISED © 2007 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.
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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.

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obligations in billions of constant FY 2007 dollars

Life sciences - split into NIH support for biomedical research and all other agencies' support for life sciences.
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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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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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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.)
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!
"For too long traditional engineering education has been characterized 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"