Engineering for a Changing World

The Future of

Engineering Practice,

Research, and Education

ISSUES
Information Technology and the Research University
The BRIDGE
In Search of Global Engineering Excellence
EDUCATING THE ENGINEER OF 2020
THE ENGINEER OF 2020
Journal of Engineering Education
ENGINEERING RESEARCH AND AMERICA'S FUTURE
INNOVATE AMERICA
National Science Board
The Science and Engineering Workforce Realizing America's Potential
RISING ABOVE THE GATHERING STORM
ISSUES
NSF's Cyberinfrastructure Vision for 21st Century Discovery
The U.S. Scientific and Technical Workforce
American Competitiveness Initiative
Leading the World in Innovation
The Vital Center
The Leadership Imperative
The World Is Flat
A BRIEF HISTORY OF THE TWENTY-FIRST CENTURY
Thomas L. Friedman
A TEST OF LEADERSHIP

Engineering Practice

Engineering Research

Engineering Education

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.

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…)

Today's Challenges

Engineering Practice

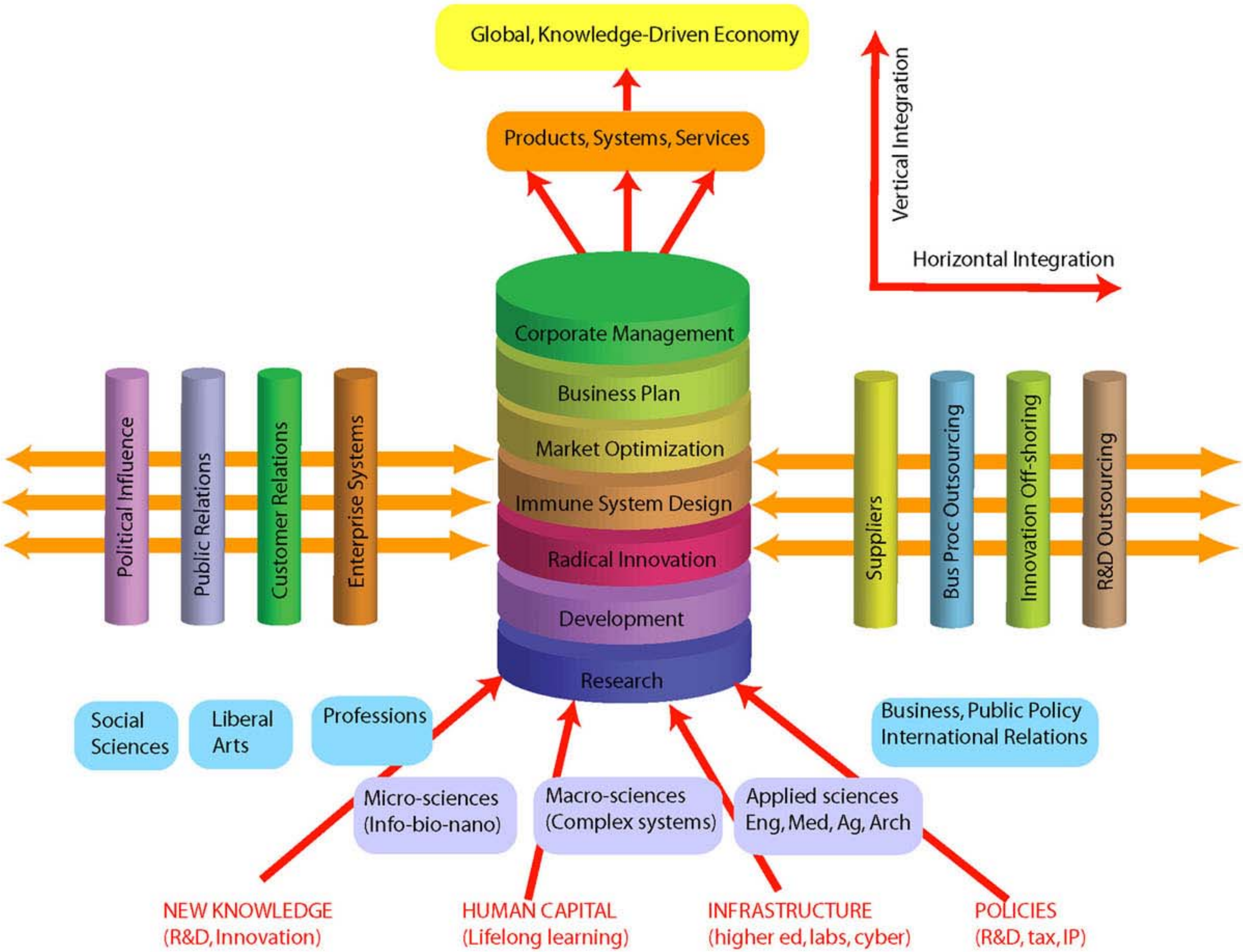
The World Is Flat

A BRIEF HISTORY OF THE TWENTY-FIRST CENTURY

Thomas L. Friedman

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
Vertical Integration
Horizontal Integration
Corporate Management
Business Plan
Market Optimization
Immune System Design
Radical Innovation
Development
Research
Political Influence
Public Relations
Customer Relations
Enterprise Systems
Suppliers
Bus Proc Outsourcing
Innovation Off-shoring
R&D Outsourcing
Social Sciences
Liberal Arts
Professions
Business, Public Policy International Relations
Micro-sciences (Info-bio-nano)
Macro-sciences (Complex systems)
Applied sciences Eng, Med, Ag, Arch
NEW KNOWLEDGE (R&D, Innovation)
HUMAN CAPITAL (Lifelong learning)
INFRASTRUCTURE (higher ed, labs, cyber)
POLICIES (R&D, tax, IP)

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 U.S. 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.

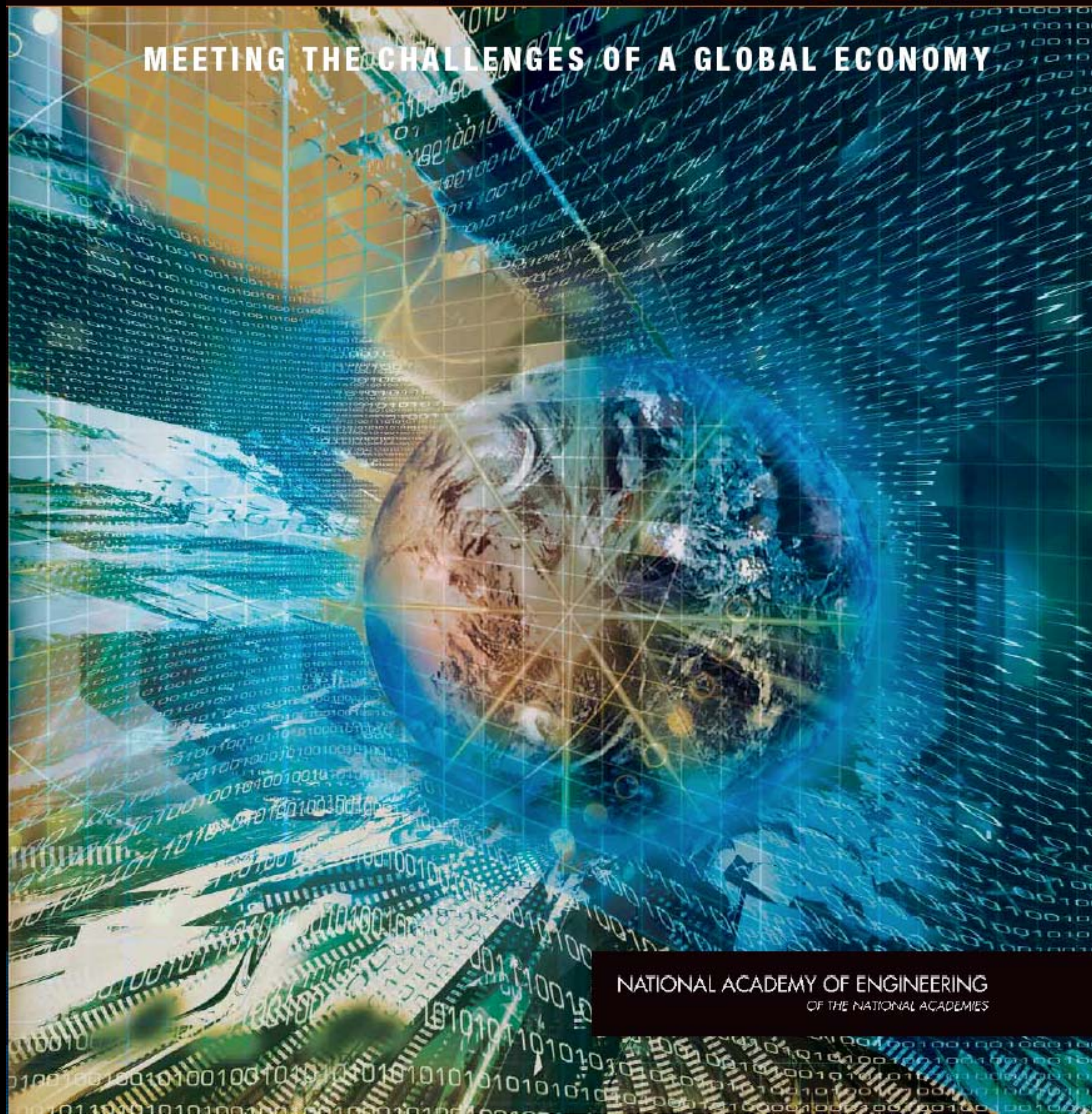
Engineering Research

Concerns

- 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.

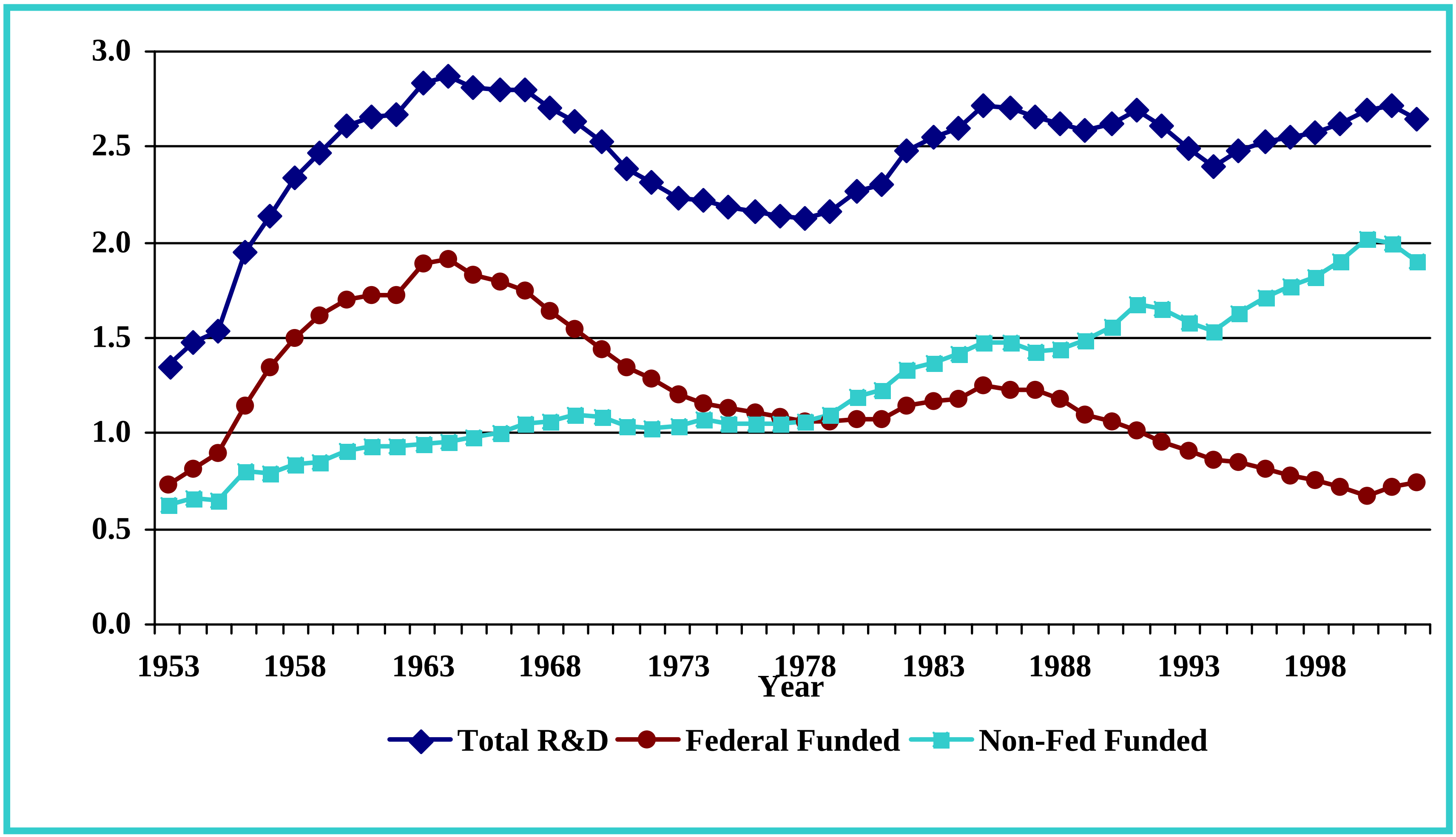
ENGINEERING RESEARCH AND AMERICA'S FUTURE

MEETING THE CHALLENGES OF A GLOBAL ECONOMY

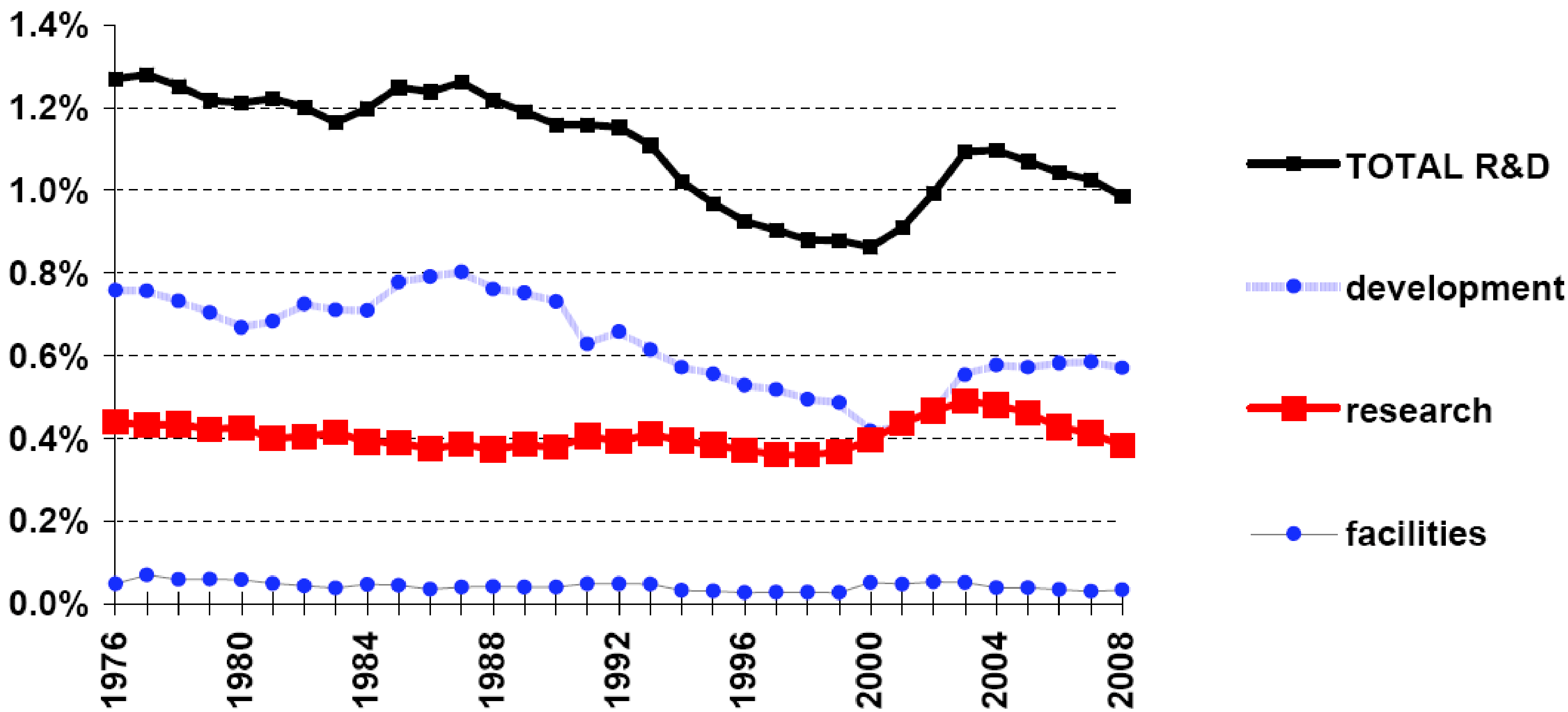


NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

Federal vs. Nonfederal R&D as Percent of GDP



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

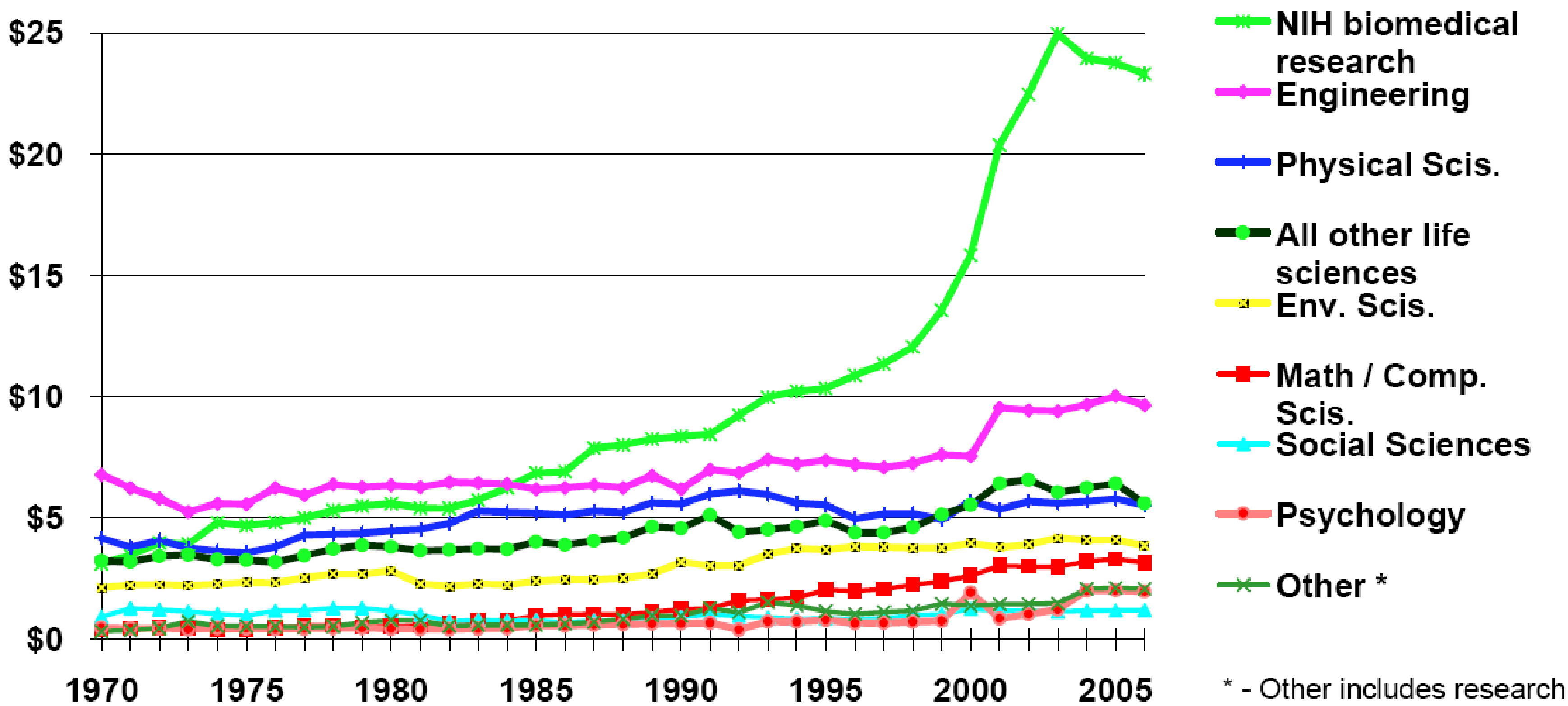


Source: AAAS analyses of R&D in annual AAAS R&D reports. FY 2008 figures are President's request. R&D includes conduct of R&D and R&D facilities. Data to 1984 are obligations from the NSF Federal Funds survey. GDP figures are from OMB, Budget of the U.S. Government FY 2008.

AAAS

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.

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).

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, e.g. with China on a five-year doubling pace.
- 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 4% 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.
- Fail 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!

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.









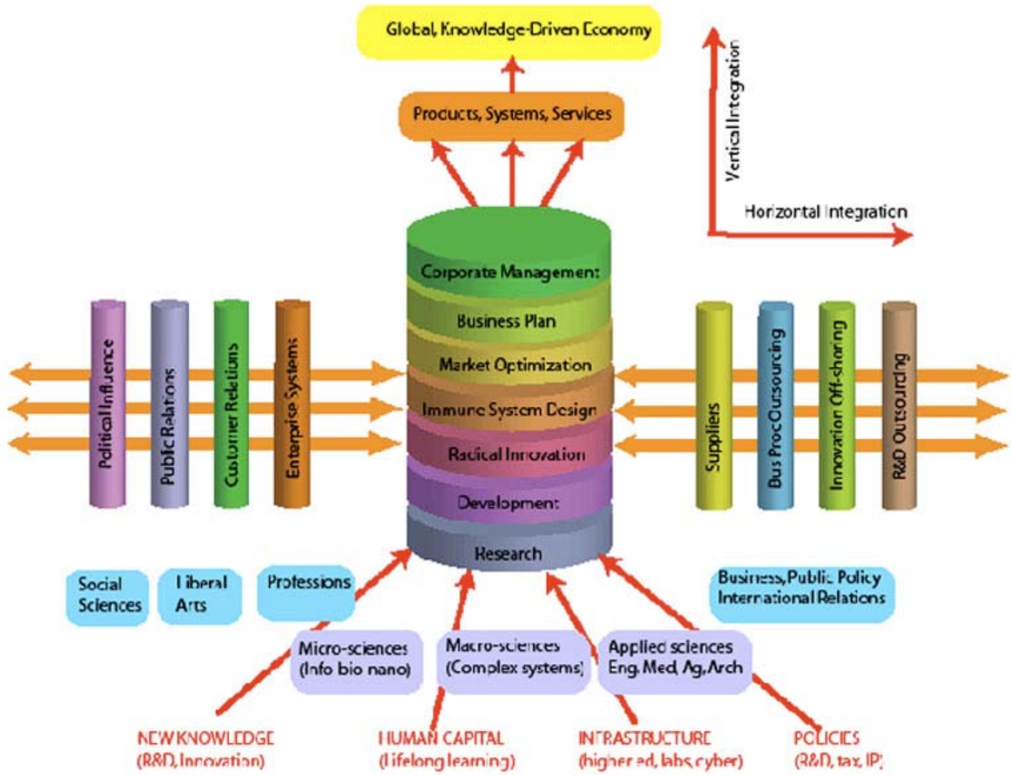

In summary, today…

- 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)

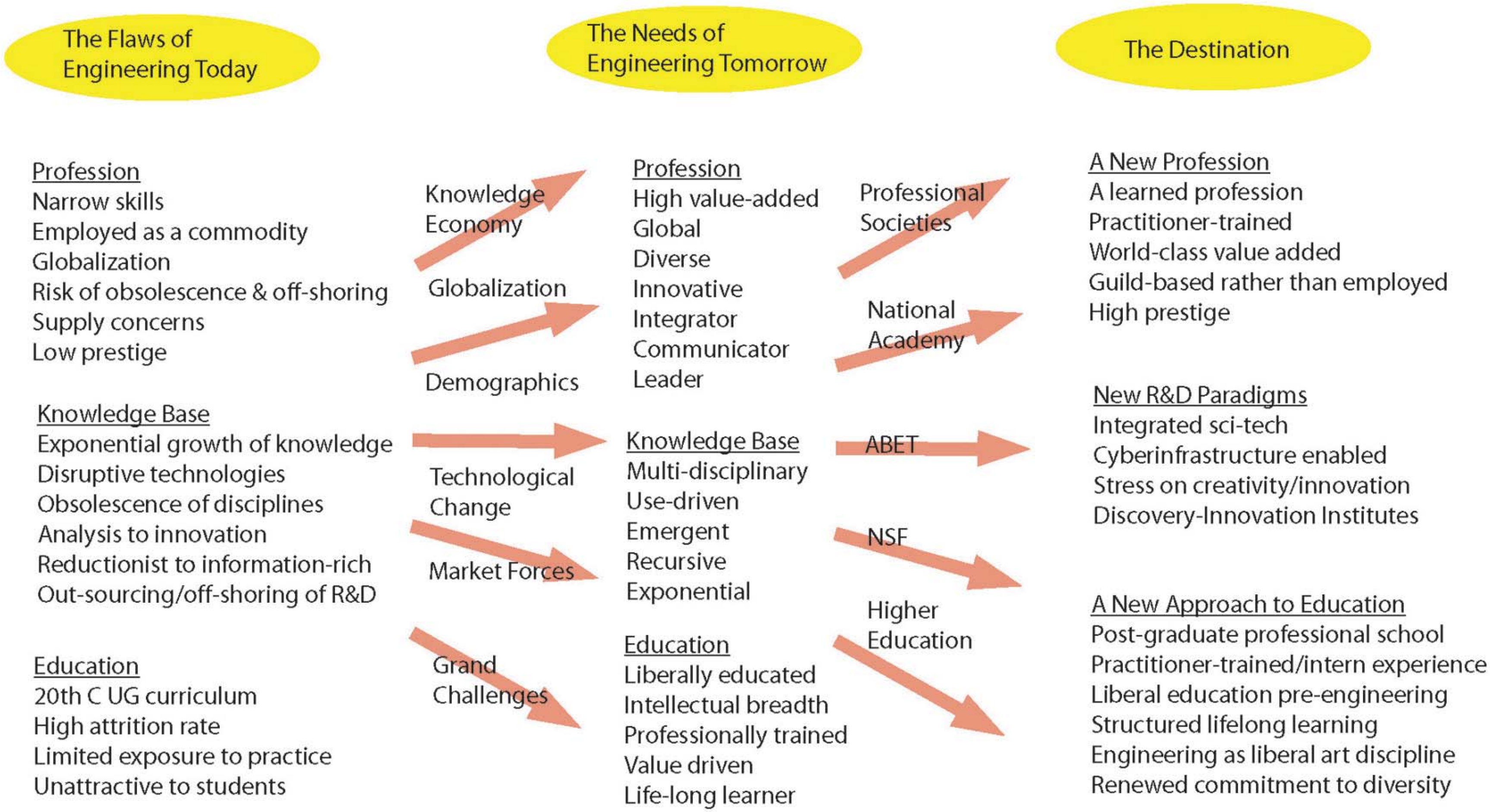
A Roadmap to 21st Century Engineering

Engineering for a Changing World

A Roadmap to the Future of
Engineering Practice, Research, and Education



The Millennium Project
The University of Michigan



The Flaws of Engineering Today
The Needs of Engineering Tomorrow
The Destination
Profession
Narrow skills
Employed as a commodity
Globalization
Risk of obsolescence & off-shoring
Supply concerns
Low prestige
Knowledge Base
Exponential growth of knowledge
Disruptive technologies
Obsolescence of disciplines
Analysis to innovation
Reductionist to information-rich
Out-sourcing/off-shoring of R&D
Education
20th C UG curriculum
High attrition rate
Limited exposure to practice
Unattractive to students
Knowledge Economy
Globalization
Demographics
Technological Change
Market Forces
Grand Challenges
Profession
High value-added
Global
Diverse
Innovative
Integrator
Communicator
Leader
Knowledge Base
Multi-disciplinary
Use-driven
Emergent
Recursive
Exponential
Education
Liberally educated
Intellectual breadth
Professionally trained
Value driven
Life-long learner
Professional Societies
National Academy
ABET
NSF
Higher Education
A New Profession
A learned profession
Practitioner-trained
World-class value added
Guild-based rather than employed
High prestige
New R&D Paradigms
Integrated sci-tech
Cyberinfrastructure enabled
Stress on creativity/innovation
Discovery-Innovation Institutes
A New Approach to Education
Post-graduate professional school
Practitioner-trained/intern experience
Liberal education pre-engineering
Structured lifelong learning
Engineering as liberal art discipline
Renewed commitment to diversity

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. Of particular importance is greatly enhancing the role of engineers both in influencing public policy and popular perceptions and as participants in leadership roles in government and business.

Conclusion 4

From this perspective the key to producing such world-class engineers is to take advantage of the fact that the comprehensive nature of American universities provide the opportunity for significantly broadening the educational experience of engineering students. 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 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 clients 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

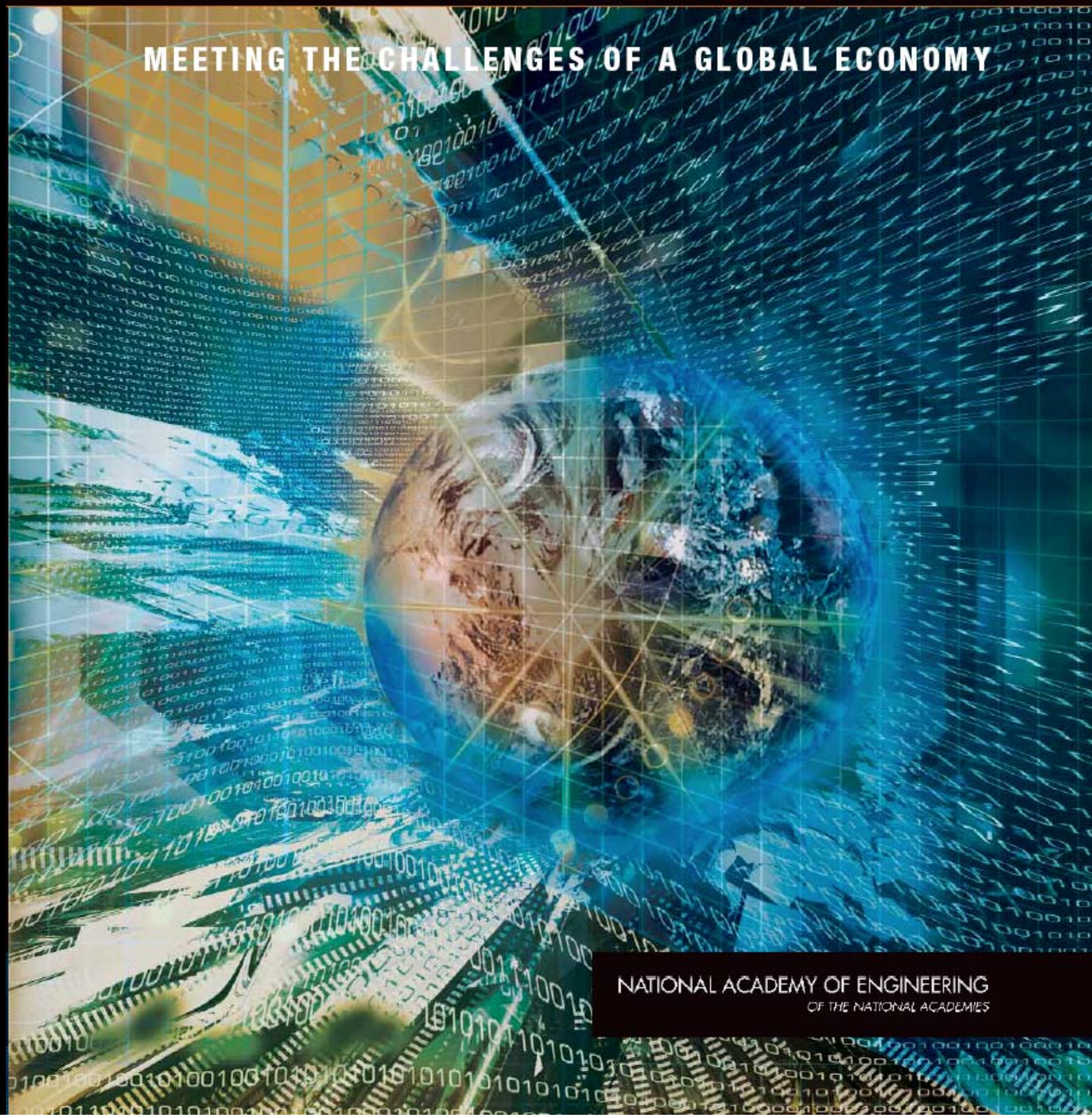
The Challenge: The great diversity among engineering professional and disciplinary societies and engineering roles that inhibits working together to develop sufficient influence at the state and federal level to elevate the status of the profession.

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.

ENGINEERING RESEARCH AND AMERICA'S FUTURE

MEETING THE CHALLENGES OF A GLOBAL ECONOMY



NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

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

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)

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.

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.

Corporate R&D Laboratory (Pfizer)

Agricultural Extension (Michigan State)

Discovery Innovation Institute???

ce

Academic Medical Center (Michigan)

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.

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.

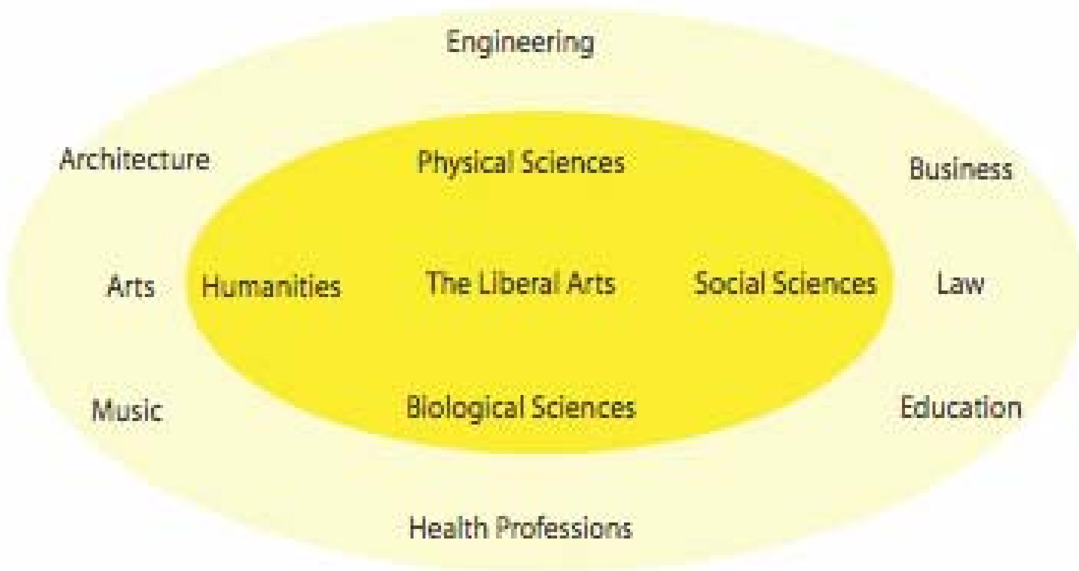
Goal 3: To achieve far greater diversity among the participants in engineering, the roles and types of engineers needed by our nation, and the programs engaged in preparing them for professional practice.

A Significant U.S. Advantage

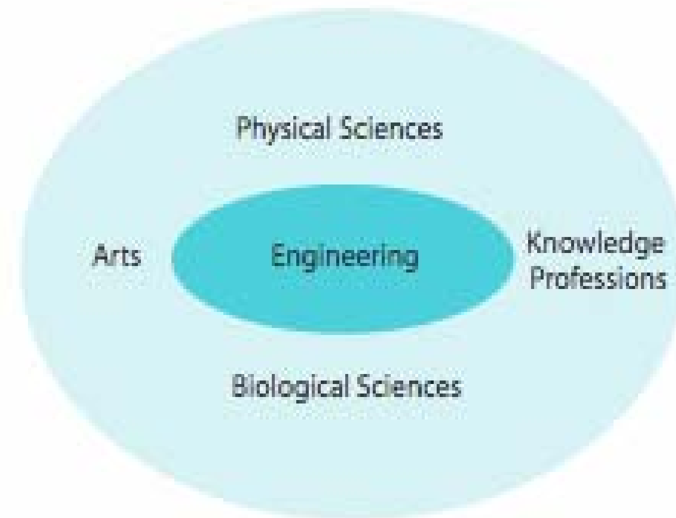
- The comprehensive nature of universities in which most engineering education occurs, spanning the range of academic disciplines and professions, from liberal arts to law, medicine, and other learned professions.
- American universities have the capacity to augment STEM education with the broader exposure 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!



Engineering as a Profession



Engineering as a Liberal Arts Discipline

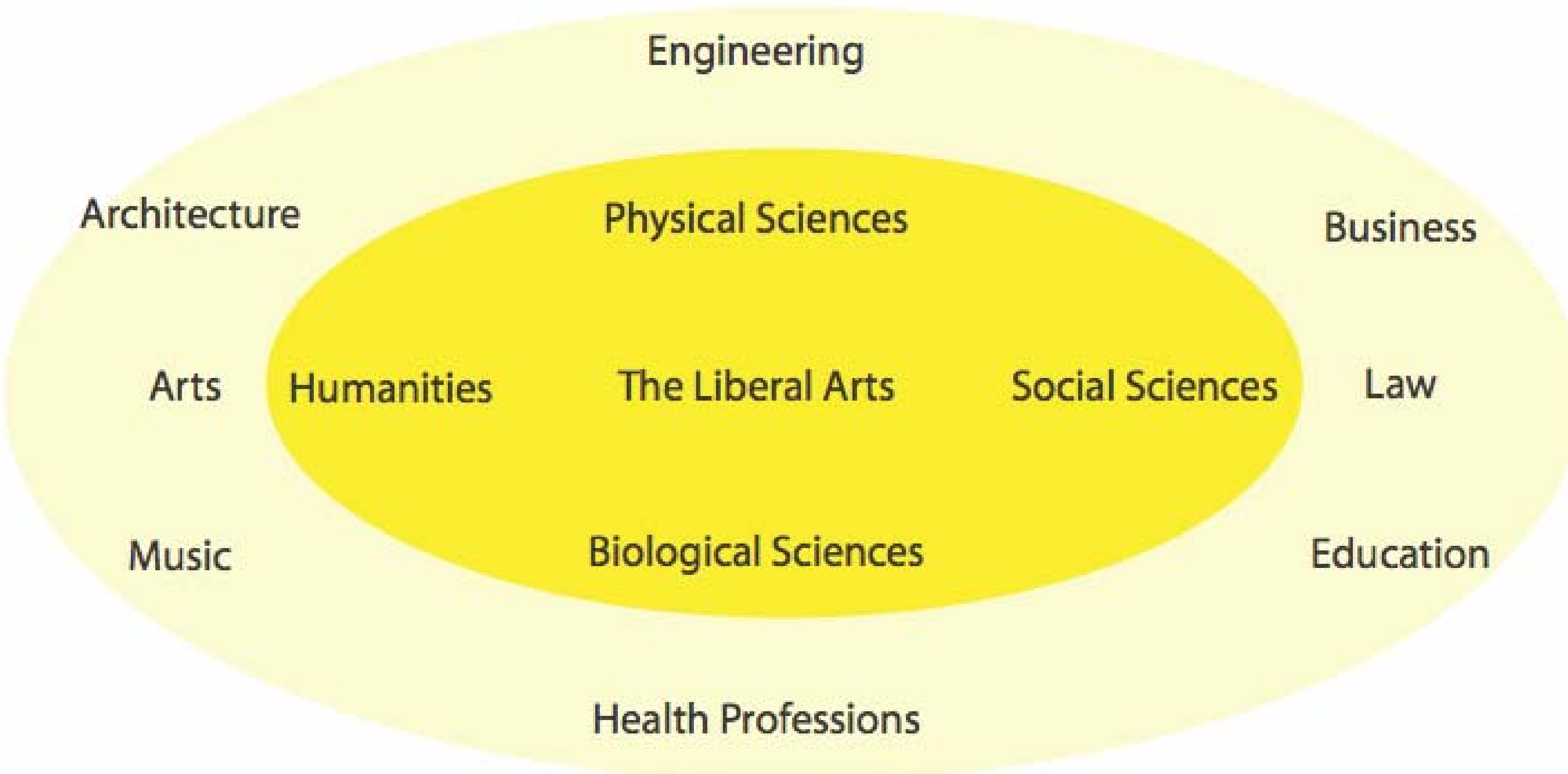
Proposed Actions

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 a broader array of undergraduate programs.
- Augmented by either internships or affiliated organizations (e.g., discovery-innovation institutes, engineering services companies).



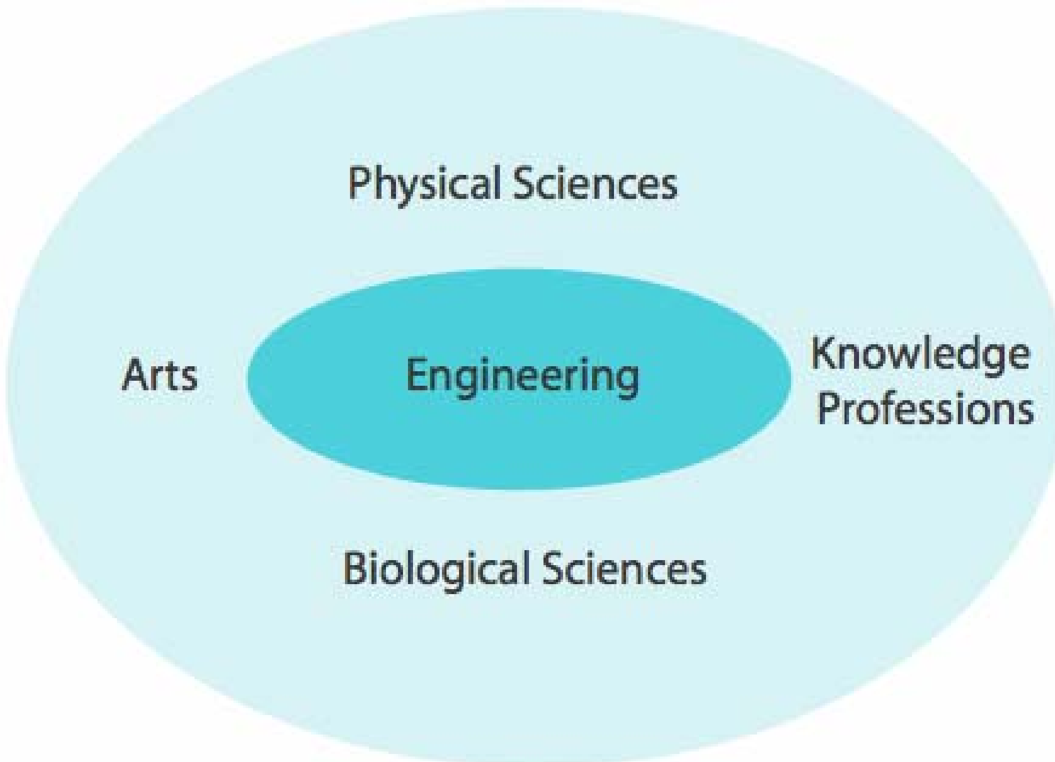
Engineering as a Profession

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 Actions (cont.)

Action 3: Working together with disciplinary and professional societies, industry, and government, engineering educators should develop a structured approach to providing lifelong educational opportunities for practicing engineers similar to those in medicine and law.

Note: This will require not only a significant commitment by educators and employers and likely as well additional licensing requirements developed by professional societies and regulatory bodies.

Proposed Action (cont.)

Action 4: The academic discipline of engineering (or, perhaps more broadly technology) should be *included in the liberal arts canon* undergirding a 21^{st} 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 "liberal 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.

Proposed Action (cont.)

Action 5: All participants and stakeholders in the engineering community (industry, government, higher education, professional societies) should commit the resources, programs, and leadership necessary to enable participation in engineering to achieve a racial, ethnic, and gender diversity consistent with changing nature of the American population.

Wm Wulf, NAE President

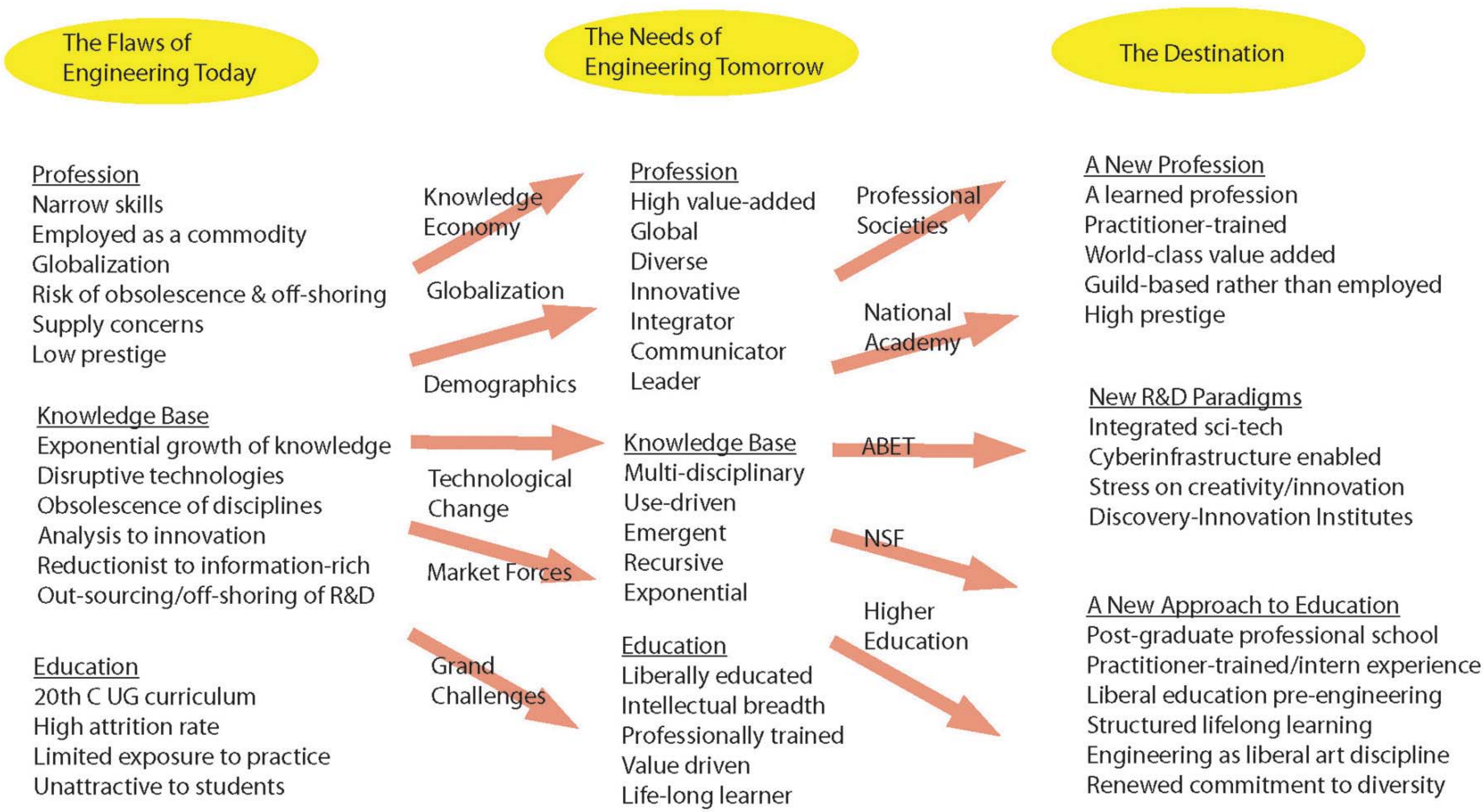
In his 2003 address to the National Academy, Bill Wulf pleaded: "We have studied engineering reform to death. While there are differences among the reports, the differences are not great. Let's get on with it! It is urgent that we do!"

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!"


The Flaws of Engineering Today
The Needs of Engineering Tomorrow
The Destination
Profession
Narrow skills
Employed as a commodity
Globalization
Risk of obsolescence & off-shoring
Supply concerns
Low prestige
Knowledge Base
Exponential growth of knowledge
Disruptive technologies
Obsolescence of disciplines
Analysis to innovation
Reductionist to information-rich
Out-sourcing/off-shoring of R&D
Education
20th C UG curriculum
High attrition rate
Limited exposure to practice
Unattractive to students
Knowledge Economy
Globalization
Demographics
Technological Change
Market Forces
Grand Challenges
Profession
High value-added
Global
Diverse
Innovative
Integrator
Communicator
Leader
Knowledge Base
Multi-disciplinary
Use-driven
Emergent
Recursive
Exponential
Education
Liberally educated
Intellectual breadth
Professionally trained
Value driven
Life-long learner
Professional Societies
National Academy
ABET
NSF
Higher Education
A New Profession
A learned profession
Practitioner-trained
World-class value added
Guild-based rather than employed
High prestige
New R&D Paradigms
Integrated sci-tech
Cyberinfrastructure enabled
Stress on creativity/innovation
Discovery-Innovation Institutes
A New Approach to Education
Post-graduate professional school
Practitioner-trained/intern experience
Liberal education pre-engineering
Structured lifelong learning
Engineering as liberal art discipline
Renewed commitment to diversity

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).

The stakes are very high!!!

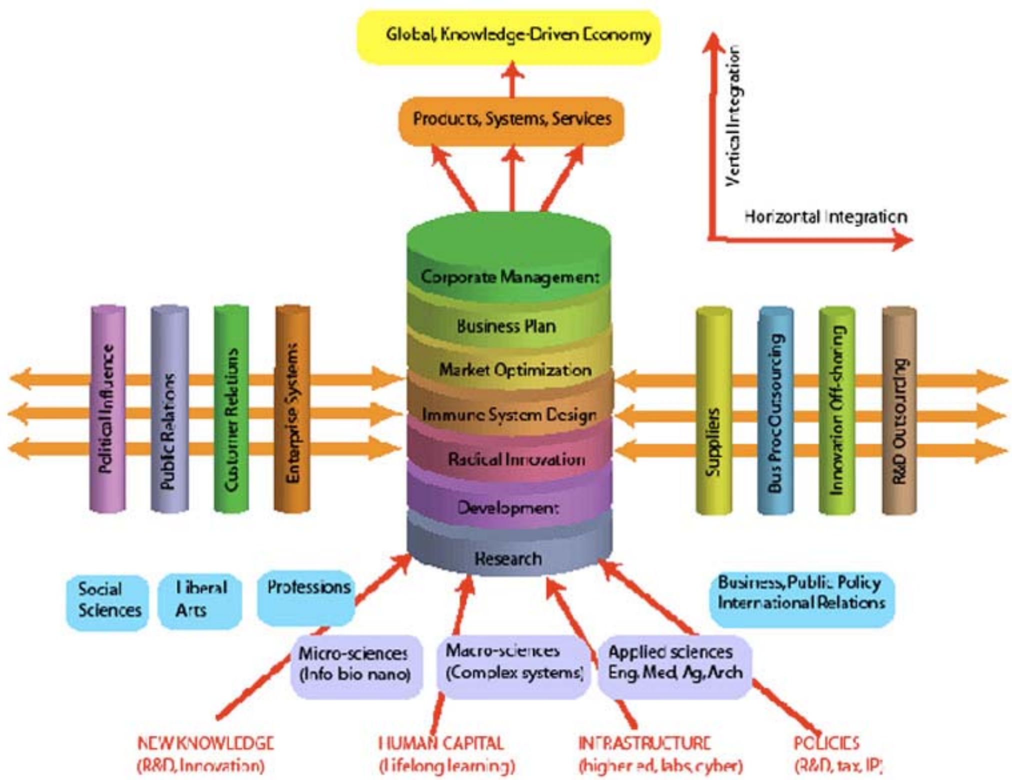
- An extrapolation of current trends such as the off shoring of engineering jobs and services, inadequate investment in long-term engineering research, inadequate innovation in engineering education, declining interest on the part of students in STEM careers, and immigration constraints raises very serious 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!

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)

Engineering for a Changing World

A Roadmap to the Future of Engineering Practice, Research, and Education



The Millennium Project
The University of Michigan

[redacted]