



Centers as a Catalyst for the Role of Education in NSF and Academe

Lynn Preston

Leader of the Engineering Research Centers Program

Division of Engineering Education and Centers

National Science Foundation

Gathering Storm in the 1980s and NSF's Role

“Strengthening Engineering in NSF,” National Academy of Engineering, 1983

- Universities have not trained engineers to grapple with larger problems of integration and technology at the systems level
- Rapid advances in technology are driving engineering toward cross-disciplinary interactions, growing need for engineering education that cuts across narrow fields
- Need for engineers with a broad understanding of design, engineering, manufacturing, and marketing to make rapid advances in technology for the US to stay competitive

1985 Engineering Research Centers Catalysts for Change

National Academy of Engineering Guidelines to
NSF - 1983

- Enhance the capacity of engineering research universities to conduct cross-disciplinary research on problems of industrial importance
- Provide students with an understanding of how engineering knowledge is converted by industry into societal goods and services

Engineering Research Centers

NAE Goals → ERC Key Features

- Build a **culture** to firmly link engineering research and education at the systems level
- Operate with **working ties with industry** --continual interaction of students and faculty with engineers and scientists in industry to assure relevance to industry and speed technology transfer
- Emphasize **synthesis of engineering knowledge** to bring requisite knowledge and methodologies to bear on **problems important to industry**
- Contribute to the **effectiveness of engineering education at all levels** with emphasis on engineering practice
- Produce **graduates who contribute innovatively** in industry

Key Features of an ERC

- **Guiding strategic vision for transforming engineered systems and the development of a globally competitive and diverse engineering workforce**
- **Strategic plans for research, education, and diversity to realize the vision**
- **Integrated, interdisciplinary research program -- fundamental to systems research and proof-of-concept test beds**
- **Integrate research and education from precollege to practitioners (courses, course modules, new degree programs)**
- **Partnership with industry/practitioners to formulate and evolve the strategic plan, strengthen research and education, speed technology transfer**
- **Leadership, cohesive and diverse interdisciplinary team, effective management**
- **Cross-institutional commitment to facilitate and foster the interdisciplinary culture and diversity of the ERC**

The Evolution of ERC Engineering Education 1985-2007

**Integrating
Discovery &
Systems**

**Center *esprit
de corps***

**Cross-
disciplinary
research
teams**

**Student
Leadership
Councils
(1990s)**

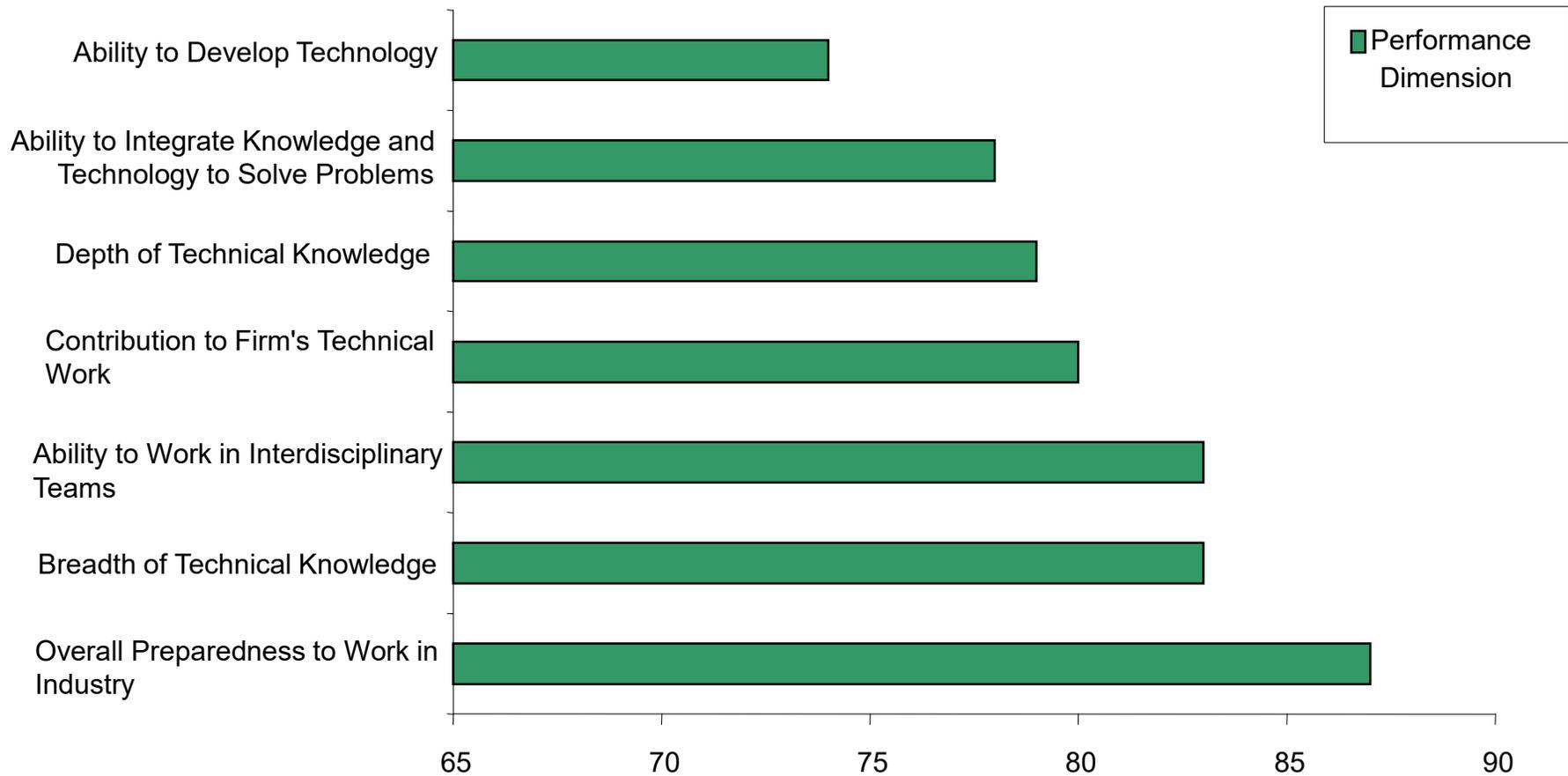


**Pre-College
Outreach
(1990s)**

**Cross-disciplinary
curricula**

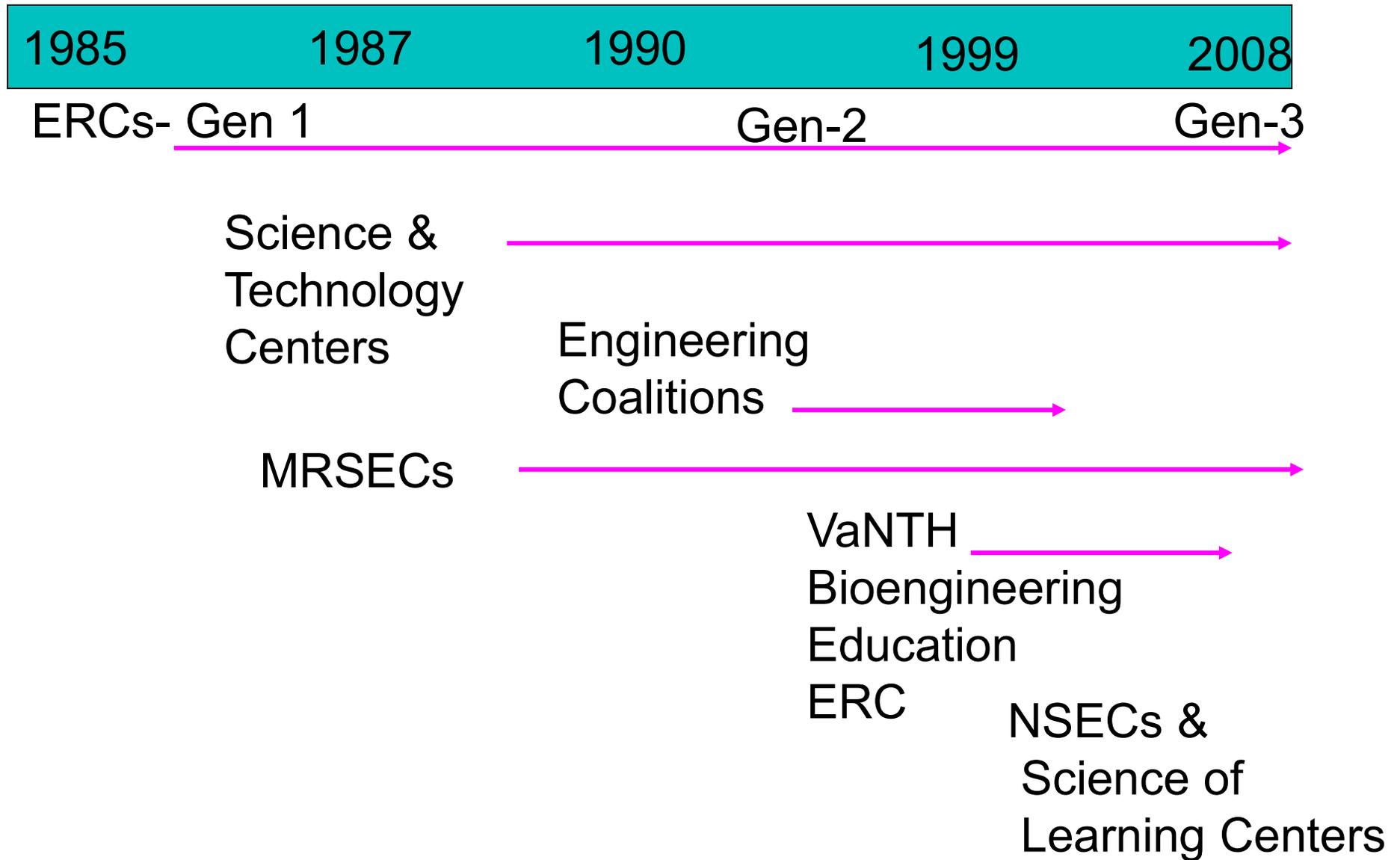
**Collaborative research
with
industry/practitioners**

Comparisons by Member Firms of Performance of ERC Graduates With Non-ERC Hires



Percentage of ERC member firms' representatives rating the former ERC students/graduates hired by their firm as "Better Than" or "Much Better Than" equivalent hires without ERC experience.

NSF's Research/Education Centers Programs



Science & Technology Centers Education Goal

STCs nurture and foster education by integrating education with research and by creating bonds between learning and inquiry so that discovery and creativity more fully support the learning process.

MRSEC Education Programs:

MRSECs education efforts have a wide scope of programs:

- Development of curricular materials from MRSEC research findings
- Renovation of middle-high school science laboratories and educating teachers
- Extensive Research Experiences for Undergraduates and Research Experiences for Teacher sites, with mentoring for REU/RET coordinators
- Networking and sharing educational resources
- Partnerships with museums and educating the general public.

NanoScience & Engineering Centers Education Goal

NSECs integrate research into the curriculum from pre-college through university to strengthen the understanding of nanoscale phenomena across the disciplines, foster the advancement of technology, and strengthen the science and engineering workforce



Science of Learning Centers Program (SLC)

Educational Goals

Integration of Research and Education

Enrich education at all levels by integrating research findings into new courses, course modules for insertion into existing courses, and new degree programs or degree options.

Application of fundamental knowledge about learning to address educational challenges

SLC Network-enabled opportunities and infrastructure to support multidisciplinary education, training and career development throughout the full trajectory of an investigator's development, from student, postdoctoral experience, to independent researchers.

Engineering Education Coalitions 1990-2000

Purpose:

- ◆ To address industry's call for graduates who are better prepared for current engineering practice, and to attract more women and minorities to engineering careers.
- ◆ Systemic reform, teams of schools, 10 years at \$2M to \$3M per year.
- ◆ Together, these schools (4 yr and 2 yr) enrolled over thirty percent of the students who were studying engineering in the U.S. at that time.

Investment: \$160 million total by the Directorate for Engineering

Assessment: SRI assessed the Coalition program after the first 5 years, finding:

- ◆ Helped to meet ABET 2000 criteria,
- ◆ Accomplished some unique successes in some universities,
- ◆ Developed some course/text materials,
- ◆ “Cannot be said to be the comprehensive and systemic new models for engineering reform anticipated,
- ◆ “Limited evidence of actual adoption outside the participating institutions.” Issues of scalability and transferability remain.

Coalitions

Key Findings - -

◆ Retention:

- ◆ Coalitions schools saw 10-25% increases in the retention rate of first-year engineering students, with even greater increases for women and underrepresented minorities.
- ◆ GPA's increased and time to degree decreased.
- ◆ No differences in graduate rates can be significantly attributed to gender.

◆ Education/Curriculum:

- ◆ Success with integration of the freshman curriculum to connect course material (math, chemistry, physics, English) to engineering practice.
- ◆ Learning communities, where students form strong academic and social relationships is also key.
- ◆ Significant collaboration among faculty along with growth in their understanding of the scholarship of teaching was required.

Driving Forces for Bioengineering Education

ERC - VaNTH

- Engineering domain knowledge became separated from pedagogy in the Coalitions over time
- Need for innovative curricula in bioengineering, an emerging field
- Could the ERC 3-Plane Strategic Planning construct do a better job of linking domain knowledge and pedagogy?
- Could integration of learning scientists with bioengineers strengthen engineering curricula and teaching/learning methods?
- Could emerging learning technology strengthen engineering teaching and learning?

**Engineering Research Center for
Bioengineering Educational Technologies at Vanderbilt**
The Next Generation in Bioengineering Education

Learning Sciences



Learning Technology



**New taxonomies, core curricula,
courses, and modules for
bioengineering education**



Bioengineering Domain Knowledge

VaNTH ERC for Bioengineering Educational Technologies Project Team

Bioengineering domain experts

Learning/Cognitive Scientists

Computer scientists

Industry and other organizations

Education specialists in evaluation & assessment



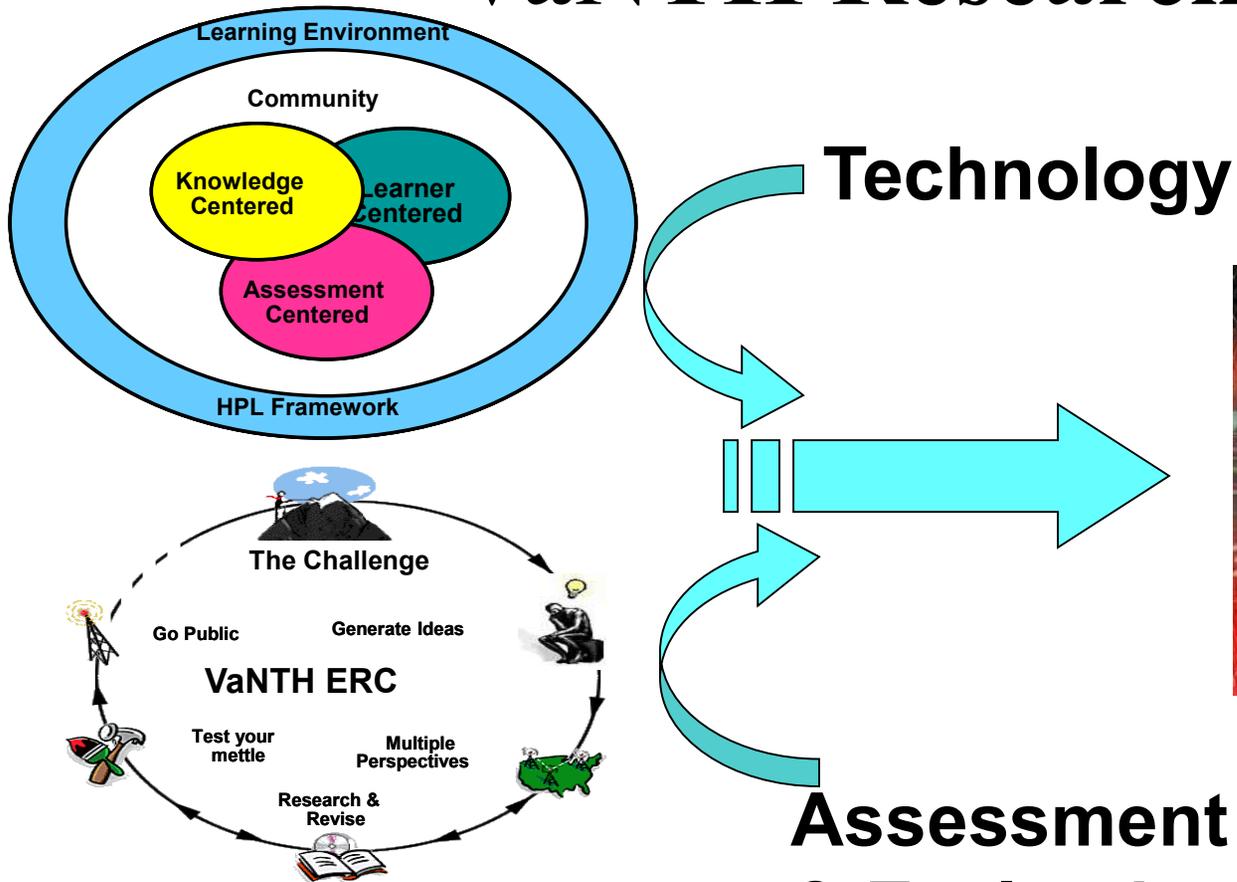
K-12 Teachers

Graduate Students

Undergraduate Students

K-12 Students

Fundamental Contribution of VaNTH Research



HPL framework and Legacy Cycle
the framework for challenge-
based instructional design



Adaptive
Bioengineering
Experts

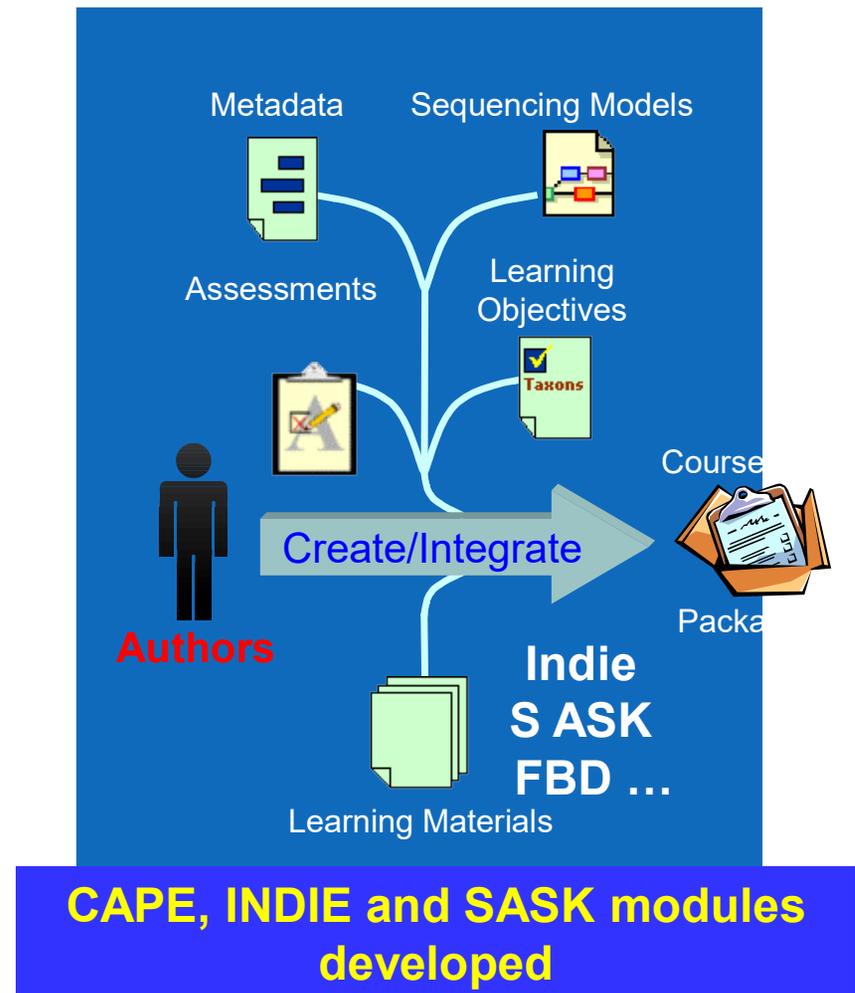
VaNTH Learning Technology

Goal: To identify, develop or discover learning technologies that can have a high impact on the the envisioned new system of bioengineering education"

Outcomes:

Technologies have been developed that provide the following:

- Formative assessments of student learning
- Aid in module design
- Assessment and evaluation of effectiveness of instruction
- Enrichment of module presentations
- Integration with other systems

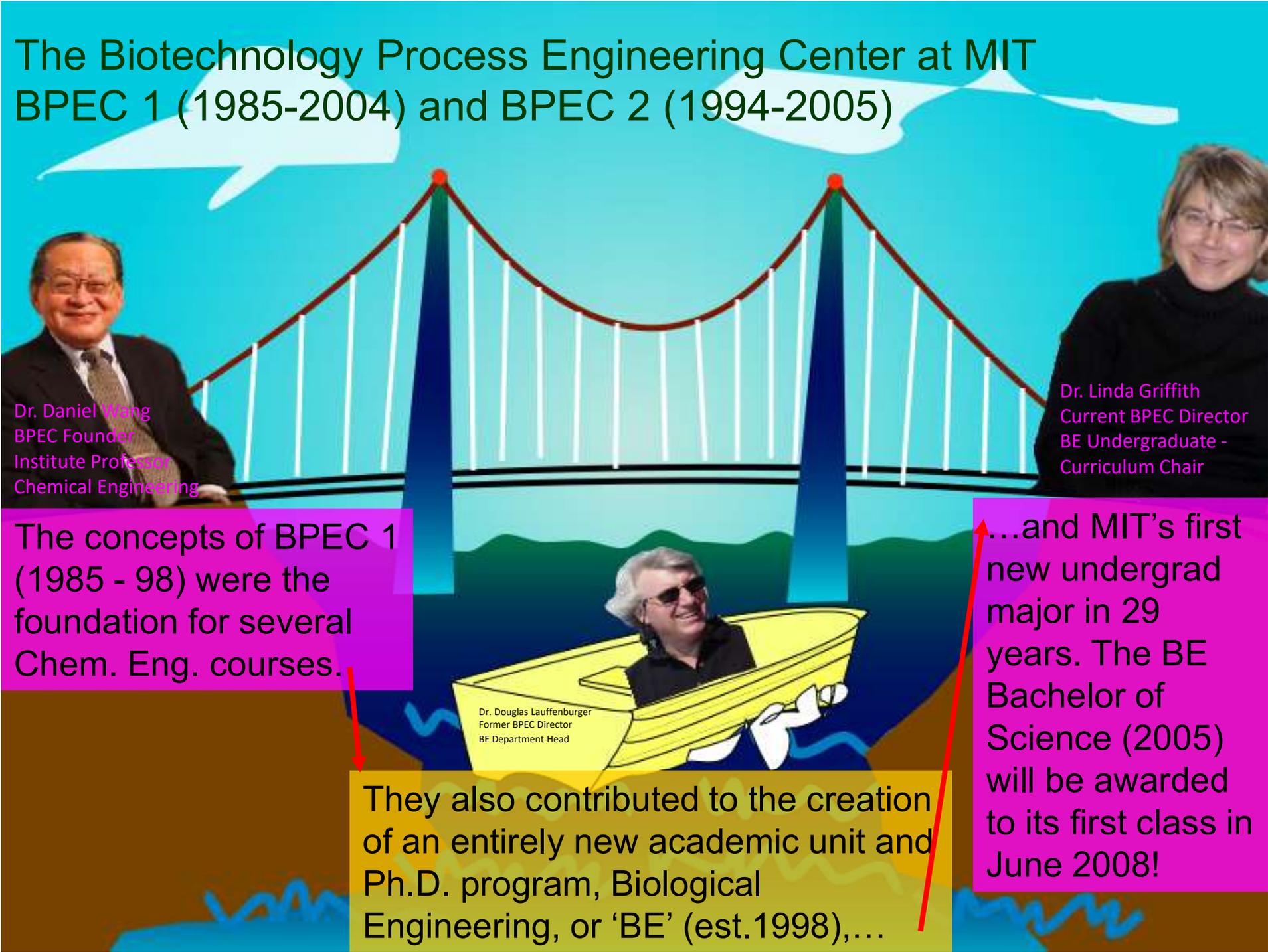


Bioengineering ERCs' New Degree /Certificate Programs

- **Biological Engineering BS Degree Program** (BioProcess Engineering Center-MIT)
- **The VaNTH Curriculum in Challenge-Based Bioengineering** (Bioengineering Educational Technologies ERC - Vanderbilt, et. al.)
- **Minor in Computer-Integrated Surgery and Specialty Course, “Surgery for Engineers”** (Computer-Integrated Surgical Systems & Technology - JHU, et al.)
- **Specialty Track in Neuroengineering in MS-BME Degree Program** (Biomimetic MicroElectronic Systems-USC, et. al)
- **Future Faculty Training Certificate in Biomaterials** (Biomaterials ERC (UWEB) - U of Washington)

The Biotechnology Process Engineering Center at MIT

BPEC 1 (1985-2004) and BPEC 2 (1994-2005)



Dr. Daniel Wang
BPEC Founder
Institute Professor
Chemical Engineering

Dr. Linda Griffith
Current BPEC Director
BE Undergraduate -
Curriculum Chair

The concepts of BPEC 1 (1985 - 98) were the foundation for several Chem. Eng. courses.

Dr. Douglas Lauffenburger
Former BPEC Director
BE Department Head

They also contributed to the creation of an entirely new academic unit and Ph.D. program, Biological Engineering, or 'BE' (est.1998),...

...and MIT's first new undergrad major in 29 years. The BE Bachelor of Science (2005) will be awarded to its first class in June 2008!

What is the Broader Impact of Interdisciplinary Research & Education through NSF Centers After 20 years?

- **Collaboration among** faculty and students across disciplines, schools, and universities and cultures is increasingly common, spawning new interdisciplinary institutes integrating science & engineering
- Faculty are **rewarded for working in groups and centers**
- **Integrated faculty career goals to advance research and education** more widely accepted in tenure and promotion policies and outcomes
- Interdisciplinary **research findings integrated into curricula**
- **Pre-college** outreach to students, **involvement of pre-college teachers in university labs** through Research Experience for Teachers Programs, more common in Engineering and Materials Science
- **Collaboration with industry** in research and education, more common in engineering

New Directions for the ERC Program and Engineering Education

FY 2004 ERC Program's Committee of Visitors

- ERC Program has been enormously successful in achieving its goals and broadly impacting industry and academe
- Reposition the ERC program for continued success and impact over the next 20 years.

US Economic Strength Challenged by Broadly Distributed Global Competence

Engineering Research and America's Future (NAE, 2005):

Committee to Assess the Capacity of the U.S.

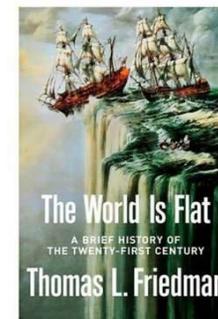
Engineering Research Enterprise

The Engineer of 2020 (NAE, 2004) and *Educating the Engineer of 2020* (NAE, 2005)

Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future (NRC/COSEPUP, 2005)

— *Innovate America: National Innovation Initiative Final Report* (Council on Competitiveness, 2005)

The World is Flat, A Brief History of the Twenty-First Century, Thomas L. Friedman, 2005



Remarks by Arden Bement at NSB Engineering Education Workshop at MIT, October 20, 2005

“Knowledge & human capital are key driving forces in global economy

Concentrations of S&T competence now more broadly distributed globally

Industry buys commodity engineers & manufacturing globally

US has to produce engineers who provide 4-5 times value added through innovation”

Major Recommendations That ERCs Can Act Upon

- Optimizing efficiency & product quality not enough, must optimize society for increased **innovation**
- Support a culture of **innovation**, a symbiotic relationship between research and commercialization, and life-long skill development
- Stimulate **diverse domestic and international talent** to pursue engineering careers in the US
- Engineering education needs to impart capacity to create & exploit knowledge for **technological innovation**
- Engineering research must **lead in bridging discovery and technological innovation**
- Engineering graduates must function in a **global world** where design and production efforts cross national borders

Gen-3 ERCs - Increase the Role of Innovation in ERCs & Academe--(NSF 07-521)

Retain ERC Key Features and:

- Engage small innovative firms in ERC's research teams
- Engage ERC students in all phases of the innovation process
- Build partnerships with academic and state and local government programs designed to stimulate entrepreneurship
- Strategically design education programs to produce creative and innovative engineers
- Provide cross-cultural, global research experiences through partnerships with foreign universities
- Build long-term sustained partnerships with a few pre-college institutions to infuse engineering concepts in the classroom

Gen-3 University Education - Newly Designed

Develop a Hypothesis & Research Design to:

- Strategically nurture and develop graduates who are **adaptive, creative innovators** with the capacity to advance fundamental knowledge and exploit it to create innovations - **New Feature**
- Structure to develop graduates who have the knowledge, skills, and experiences needed to be **successful in a globally connected, innovation-driven world**- **New Feature**
- Include development of new course materials derived from ERC's interdisciplinary and systems research, and if suitable, degree programs and options
- **Strategic plan specifies desired characteristics**, proposes how education program will impart these to students, and how it will **measure and assess progress and impacts** through longitudinal data - **New Feature**

Pre-College Education Newly Designed

- **Long-term partnerships** with a small number of pre-college institutions (middle and high school) that are committed to - New Feature:
 - Including engineering concepts in pre-college education;
 - Increasing the enrollment of pre-college students in college-level engineering degree program;
 - Increasing the diversity of students interested in engineering
- Involve **pre-college teachers in ERC's research** to enable them to develop course modules to bring engineering concepts to the pre-college classroom (an ERC RET Program within the core effort)
- Offer promising high school students a “**Young Scholars**” “research opportunity in the ERC's laboratories - New Feature
- ERC's **faculty and students will participate in pre-college activities as mentors** and their efforts will be recognized and rewarded by their administrations - New Feature

New Directions for Undergraduate and Ph.D. Engineering Education

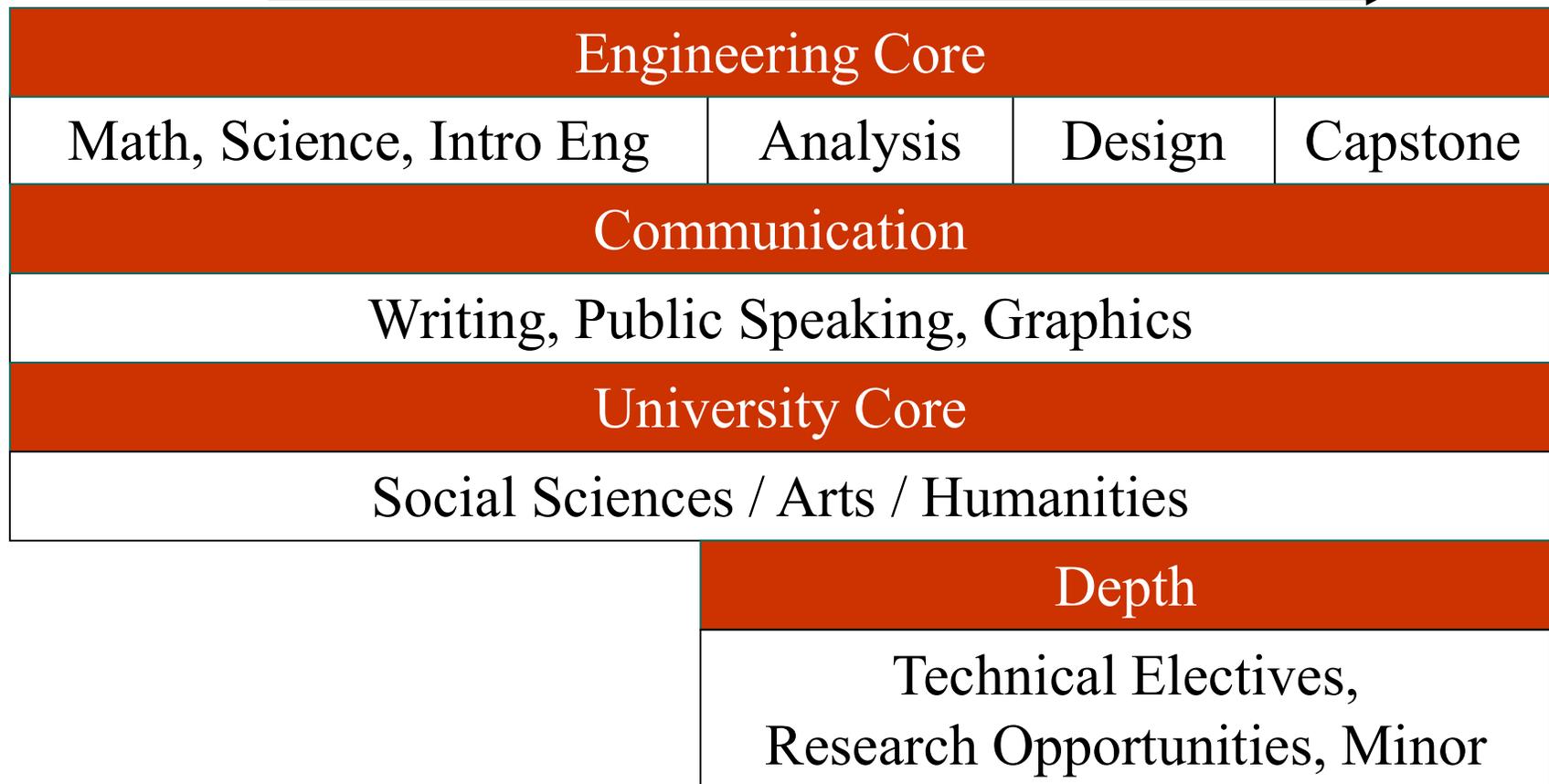
“Rising Above the Gathering Storm” and other Study Recommendations

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Traditional Engineering Curriculum

Freshman

Senior



Common First-Year Curriculum

| | Fall Semester | Spring Semester |
|--|--|-----------------------------|
| | Introduction to the Study of Engineering | |
| | Engineering Design | Engineering Problem Solving |
| | Calculus 1 | Calculus 2 |
| | Chemistry 1 | Physics 1 |
| | Elective | College Writing 1 |

What Lies Ahead for Undergraduate Engineering Education?

Creativity and Innovation, Based in Fundamentals

- Combining field-specific scientific & engineering fundamentals with knowledge across disciplines
- Curricula designed to stimulate creativity not proficiency in problem solving
- Product-development/innovation experiences
- Exposure to entrepreneurship

What Lies Ahead for Undergraduate Engineering Education?

Creativity and Innovation, Based in Fundamentals

- **Overall depth of knowledge** of physical, life, and social sciences, mathematics and statistics
- Added depth of **knowledge in interdisciplinary clusters** of fields that supports career goals - room to create own degree pathway through electives & minors
- Early and continual experience in **designing technology, exploring technology opportunities** in context of client and market needs - not problem solving when solution is known by professor
- Experience **taking risks**, working in areas with unknown solutions, exploring alternatives, failing and succeeding
- Experience **working in teams** across engineering and other disciplines
- Specialized courses designed for engineers in **business planning**, business development, and management

Is the Engineering PhD Driven by the Market Place or by the Need for a Workforce for Academic Laboratories?

- 7000 Engineering Ph.D.s (1997)
 - 52% to US Citizens & Permanent Residents
- 7300 Engineering Ph.D.s in (2005)
 - 42% to US. Citizens, Permanent Residents
- 30% of Ph.Ds go into into Academia
- M.S graduates earn more than Ph.D graduates, after 5 years). Has the “marketplace spoken?

Is the Engineering PhD Driven by the Market Place or by the Need for a Workforce for Academic Laboratories?

Today's Ph.D. is and tomorrow's industrial innovator (70%) and tomorrow's faculty (30%) , **however**

- Ph.D. education is a “by-product” of research business (PI is both employer and advisor)
- Ph.D. has depth but lacks breadth across disciplines, little or no experience with innovation
- Ph.D. graduates find little financial value added over an MS degree upon entry in industry, benchmarked with Law, Medicine and Business

Desired Attributes of a Ph.D. in Engineering for the Academic and Industrial Marketplace

- **World-class knowledge** in a relevant specialty and related areas
- Understand **how specialized knowledge aligns with the larger context** of knowledge, technology, and systems
- Experience with the **innovation** process
- Experience **across disciplines and cultures**
- **Awareness of global marketplace** for research and technology
- **Leadership and mentoring capabilities**, ability to articulate ideas, work in teams
- Ability to **define and address opportunities** and problems
- Ability to be both a **thinker, a strategist, and a doer**

What Lies Ahead for Ph.D Engineering Education? Creativity and Innovation Based in Fundamentals

- Design the Ph.D. degree to position graduates for productive careers in industry or academe as innovators, not just to provide workers for academic research laboratories
- Deepen knowledge in chosen field, add knowledge across engineering and other disciplines needed to advance thesis and careers goals
- Experience designing and developing systems in cross-disciplinary teams that include industry, other users, foreign collaborators
 - Define opportunities and understand user/market needs
 - Explore transforming research findings into technology - innovation
 - Experience with user communities (industry, public decision makers, physicians)
 - Engage in the technology/product development process in partnership with small or large firms or practitioners to understand innovation
- Specialized courses in business planning and development...not a full MBA