Rethinking Engineering Education From the Ground Up

Richard K. Miller, Ph.D.
President
Franklin W. Olin College of Engineering
Needham, MA 02492

Invited Keynote Presentation

Implementing Project-Based Learning In Engineering Education

Skolkovo Institute of Science and Technology
Moscow, Russia
18 October, 2012

Outline

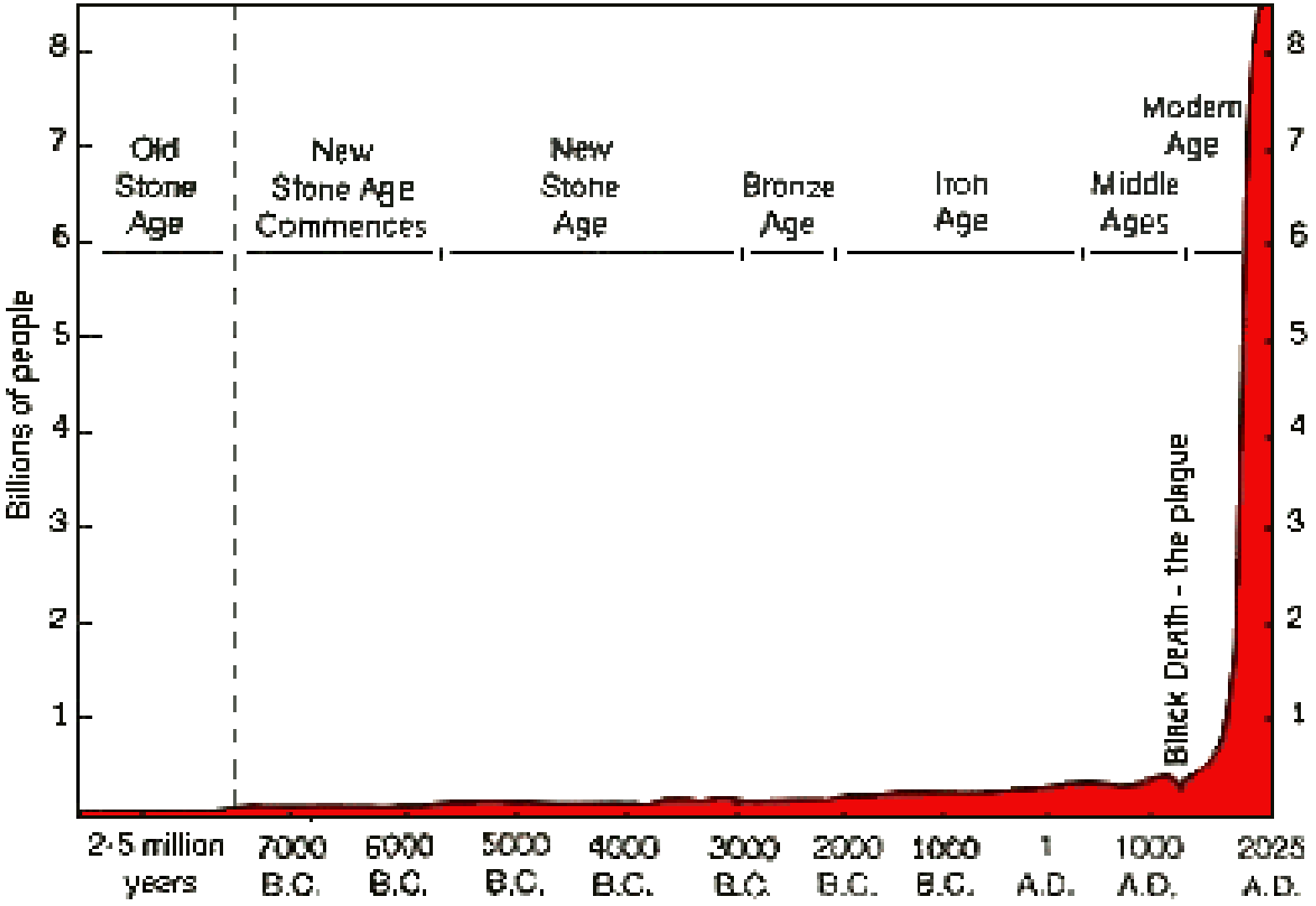
1. Why education must change

2. What changes are needed

3. A new model for engineering education

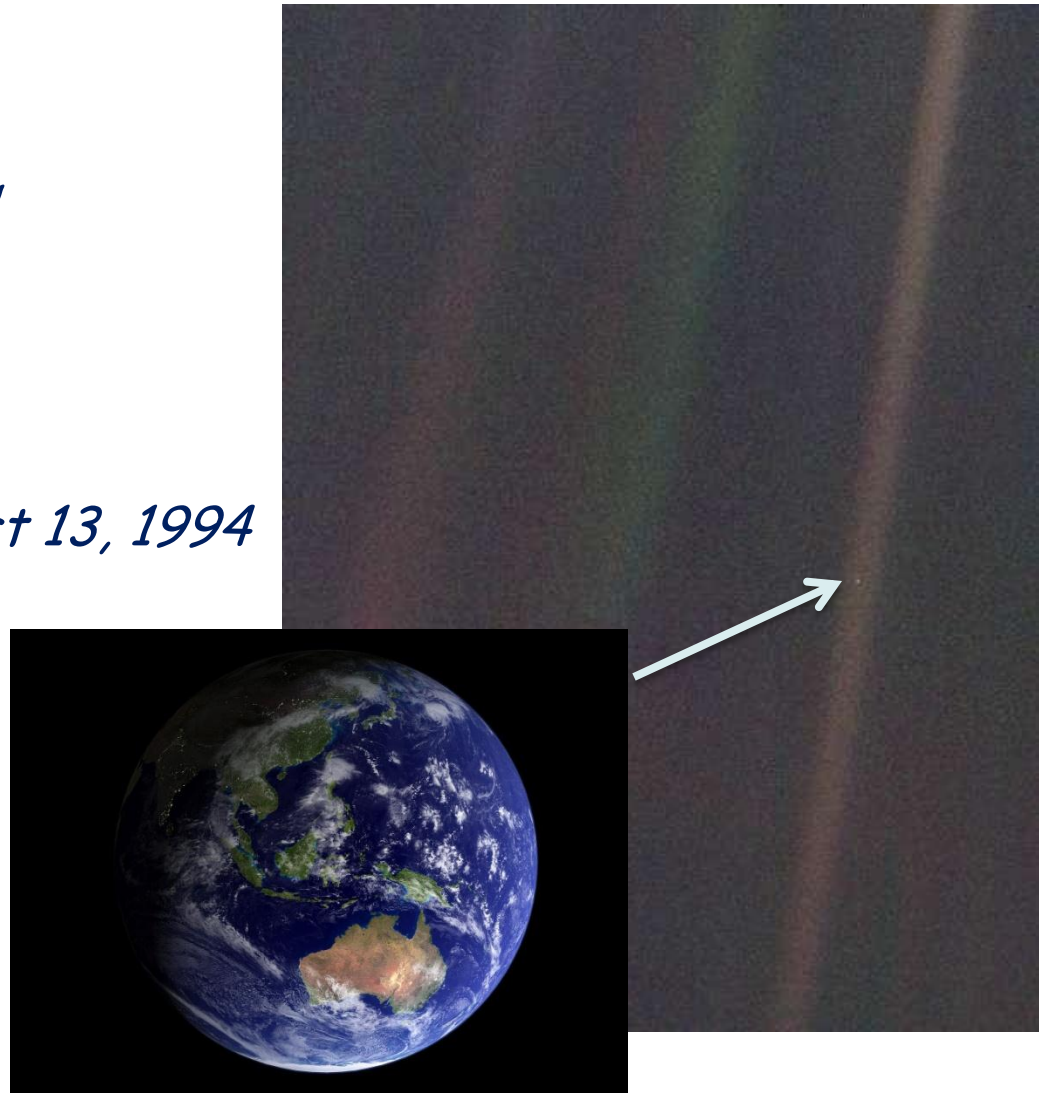
1. Why education must change

World Population Growth Through History



The Pale Blue Dot

- *NASA, 1990 – Voyager 1*
- *3.8 billion miles (41 AU)*
- *Carl Sagan – address at Cornell University, Oct 13, 1994*



Looking Back to the 20th Century:

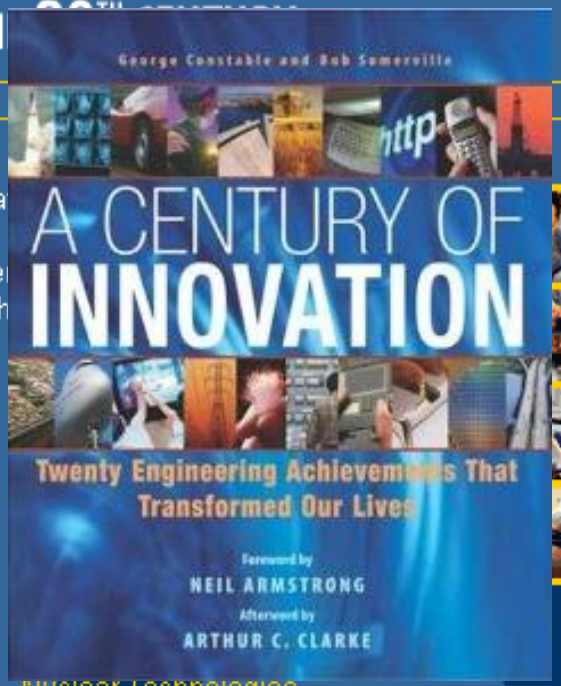
Greatest Engineering Achievements OF TH

◆ About ◆ Timeline ◆ The Book

Welcome!

How many of the 20th century's grea
achievements will you use today? A
Explore our list of the top 20 achieve
engineering shaped a century and ch

1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11.
12.
13.
14.
15.
16.
17.
18.
19. Nuclear Technologies
20. High-performance Materials

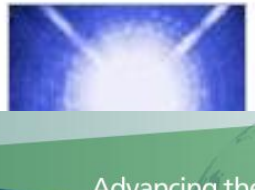


Greatest Achievements

NAE Grand Challenges for the 21st Century

Security, Sustainability, Health, Joy of Living

Make solar energy economical



Provide energy from fusion

Develop carbon sequestration methods

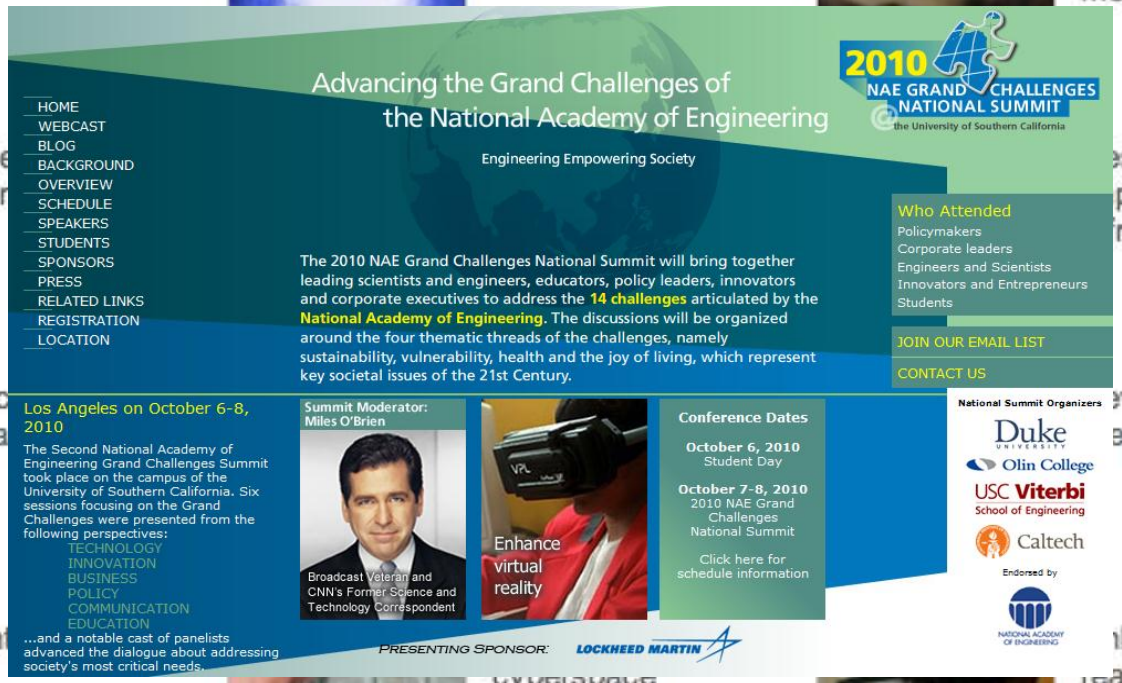
Manage nitrogen

Advanc informa

Prevent terror

Advance personalized learning

Engineer the tools of scientific discovery



Challenges of the 21st Century:

- Complexity
- Transcend time zones,
  political boundaries,
  disciplinary boundaries
- Require systems thinking and
  unprecedented cooperation

Examples: acid rain, traffic in Stockholm

2. What changes are needed in education?

Education must meet basic needs in every generation

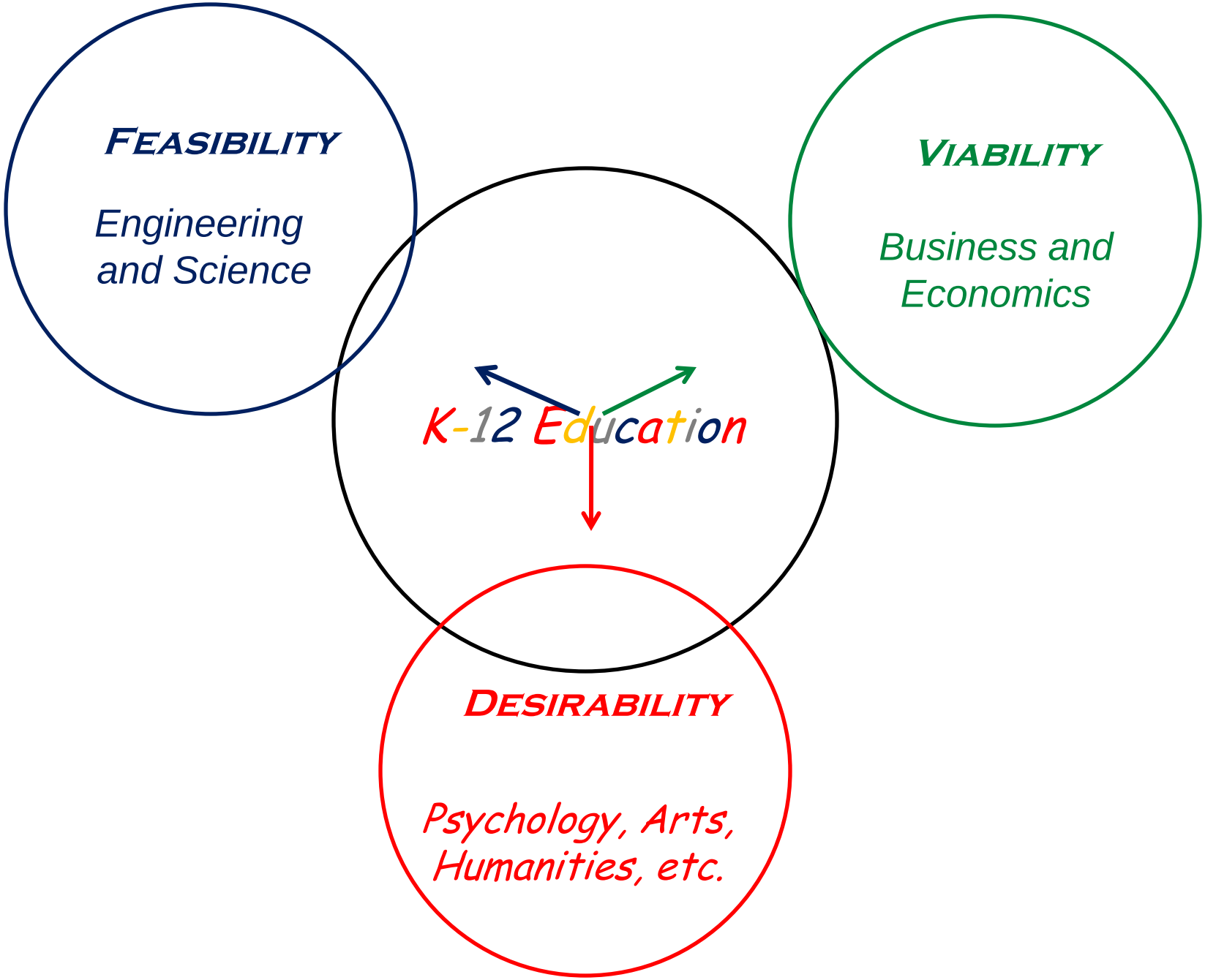
- **To be the most important person to someone else**
  - ***Increase in single parent families***
- **To make sense of your surroundings**
  - ***Decline in STEM competence***
- **To manage the grand challenges of your age**
  - ***Complexity is overwhelming: “can’t do”***
- **To make a positive difference in the world**
  - ***Decline in common values and empathy***

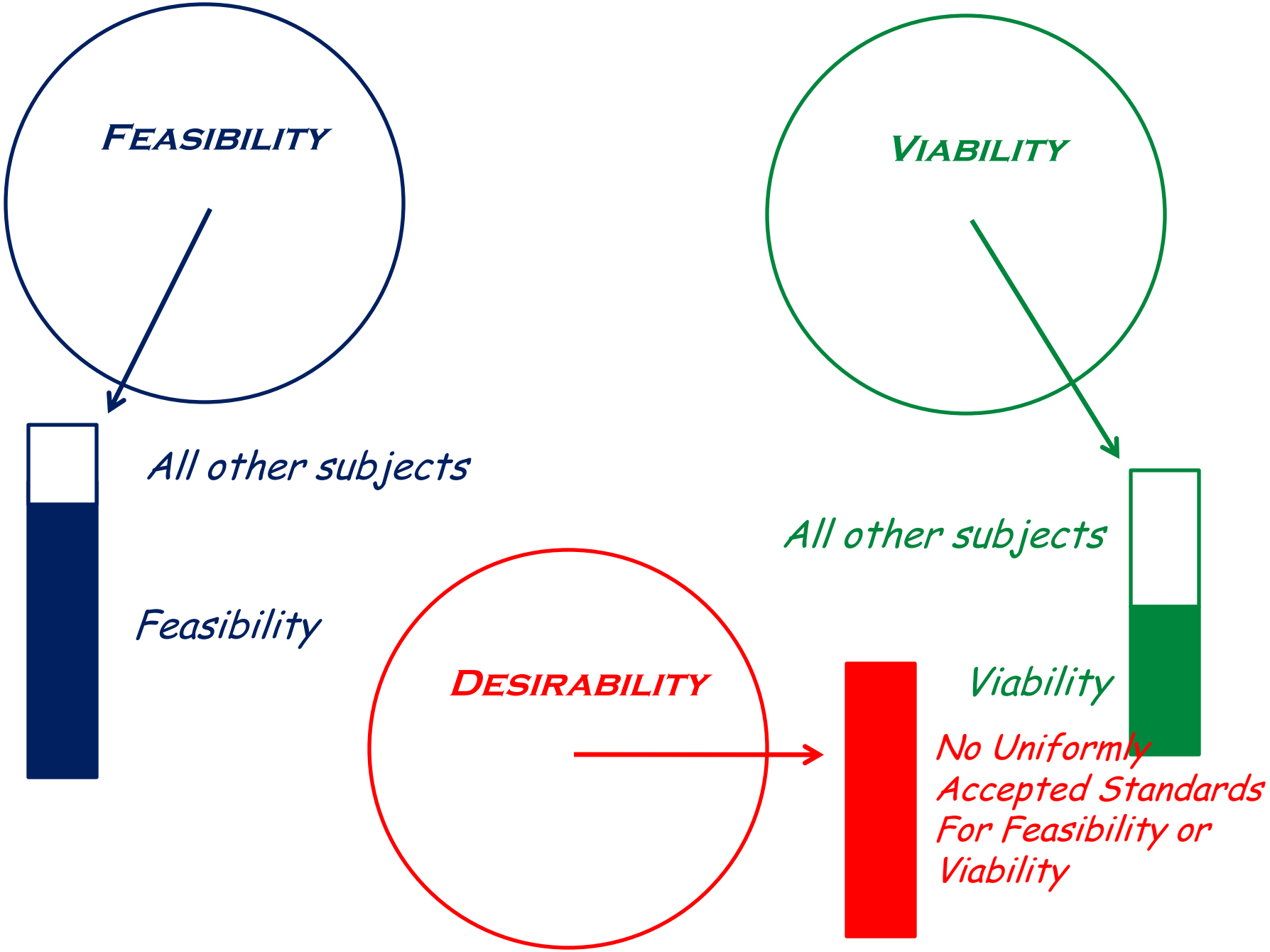
Conclusions:

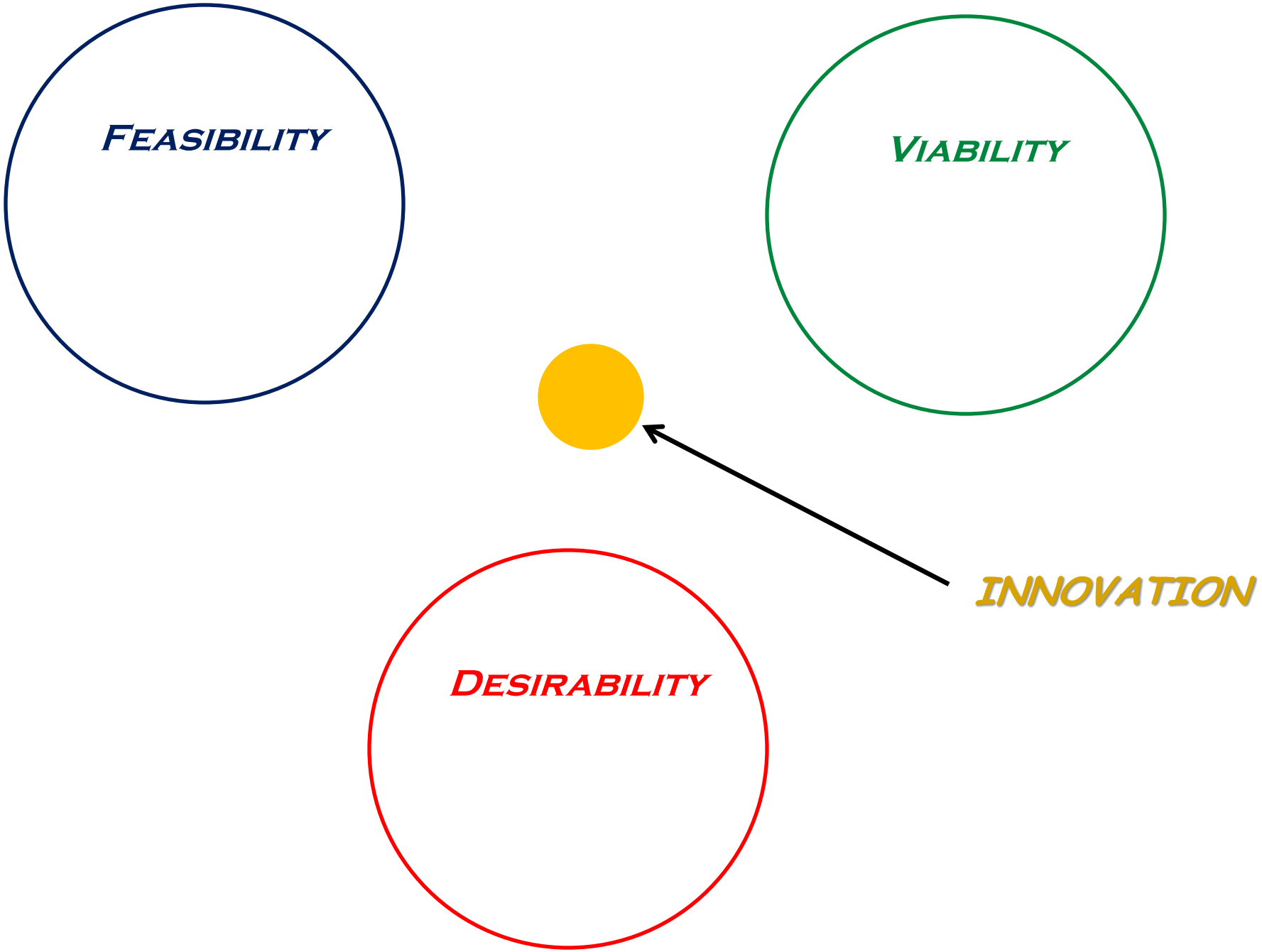
- Technological innovation is our best hope
- Perhaps now *creativity* is as important as knowledge
- We need more engineering ***innovators*** for the 21st century

BUT,

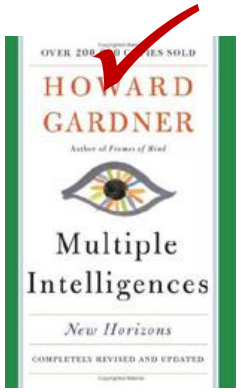
Our traditional approach to higher education may be preventing us from producing innovators!

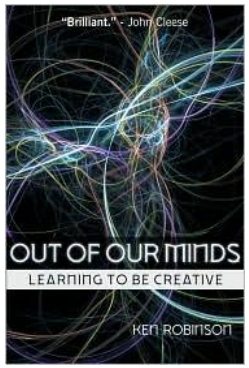

FEASIBILITY
Engineering and Science
VIABILITY
Business and Economics
K-12 Education
DESIRABILITY
Psychology, Arts, Humanities, etc.

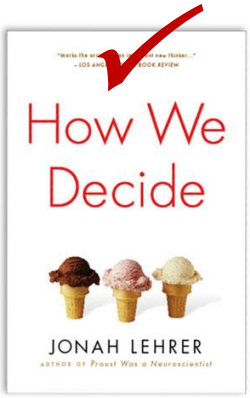

Feasibility
All other subjects
Feasibility
Viability
All other subjects
Viability
Desirability
No Uniformly Accepted Standards For Feasibility or Viability

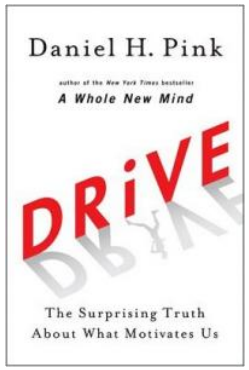

FEASIBILITY
VIABILITY
INNOVATION
DESIRABILITY

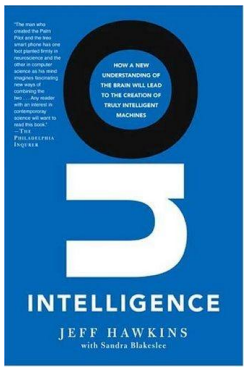
Creativity & Cognition

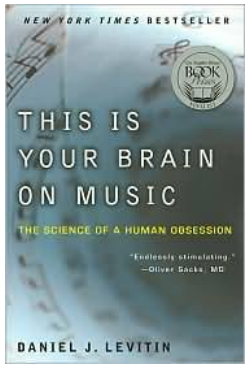


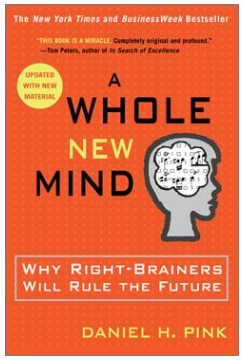


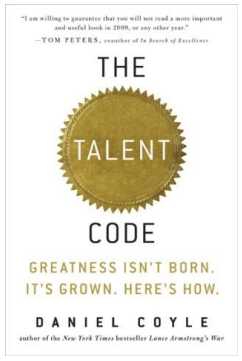


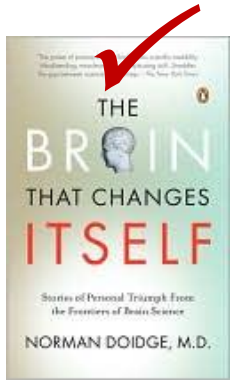


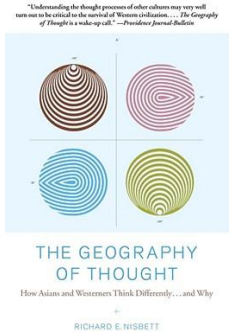






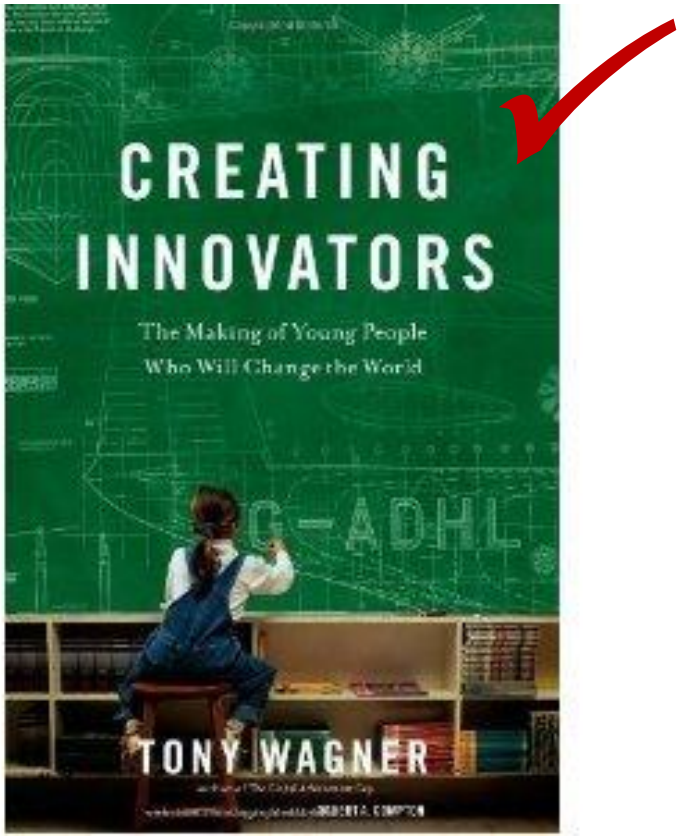






YOUTUBE:
Sir Ken Robinson (TED 2006)

Creativity & Cognition



Multiple Intelligences: Howard Gardner, Frames of Mind (1983)

- All people have at least 7 "intelligences"
  - Linguistic
  - Logical/mathematical

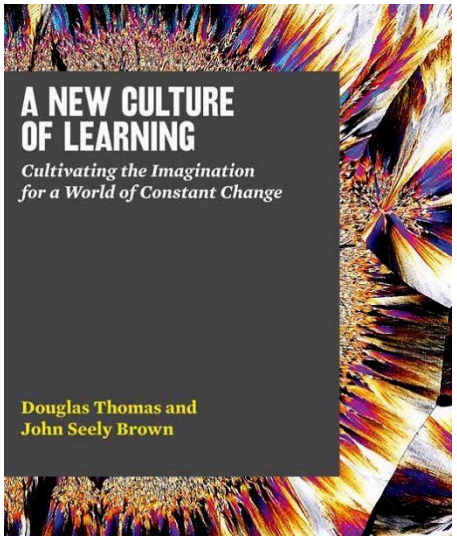
  Academic Intelligence (IQ, SAT, etc.)
  - Spatial
  - Bodily-kinesthetic
  - Musical

  Artistic Intelligence
  - Interpersonal
  - Intrapersonal

  Persuasion, Management

A New Culture of Learning

Traditional	New
Knowledge Transfer	Construct Knowledge
"Can't Do"	"Can Do"
Follow Orders	Follow Your Passions
Learn in Class	Learn 24 x 7
Learn Alone	Learn in Teams
Problem-based	Design-based



Pedagogy like Graduate School

"For most of the twentieth century our educational system has been built on the assumption that teaching is necessary for learning to occur."

What We Teach vs. What They Need to Know

- ***Engineering alumni report that engineering science is not as useful in their careers as design, communication, teamwork, and entrepreneurial thinking*** *(Kristen Wolfe, "Understanding the Careers of the Alumni of the MIT Mechanical Engineering Department," SB Thesis, June, 2004, MIT (supervised by Prof. Warren Seering)).*

- *Prof. Woodie Flowers, "Man Who Waits for Roast Duck to Fly Into Mouth Must Wait a Very Long Time," Engineer of the Future 2.0, Olin College, April 1, 2009.*

YouTube: Prof. Woodie Flowers on Education Reform

Prof. Warren Seering

Kristen Wolfe
June, 2004
S.B. Thesis

Understanding the Careers of the Alumni of the MIT Mechanical Engineering Department

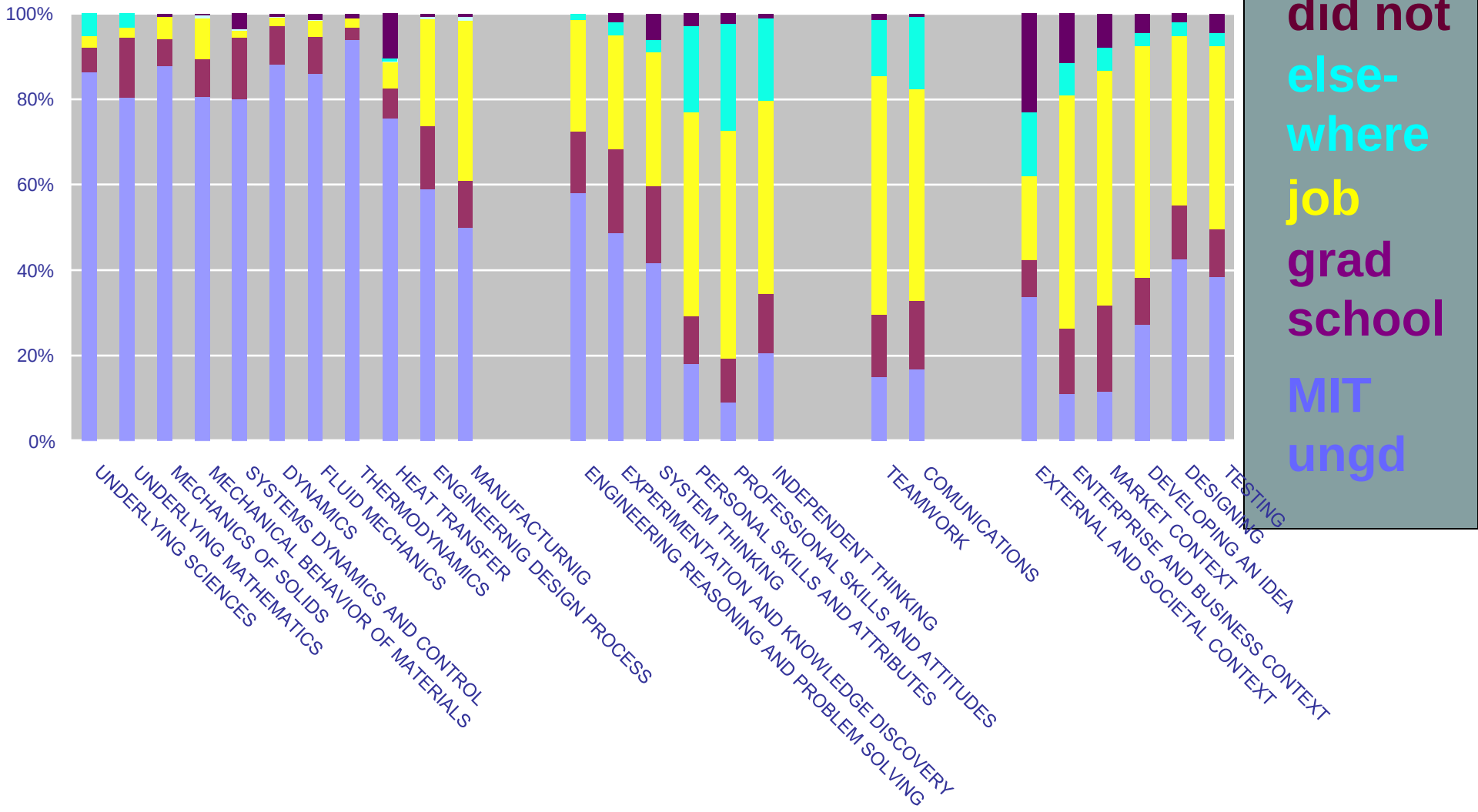
Taken from “Man who waits for roast duck to fly into mouth must wait a very long time,” Presented by Prof. Woodie Flowers, MIT, on April 1, 2009, at Engineer of the Future 2.0, Olin College, Needham, MA. (Used with permission; video available on WWW)

survey

MIT
ME Graduates
1992 - 1996

676 e-mail requests
308 completed the survey
46% response rate

Source


100%
80%
60%
40%
20%
0%
UNDERLYING SCIENCES
UNDERLYING MATHEMATICS
MECHANICS OF SOLIDS
MECHANICAL BEHAVIOR OF MATERIALS
SYSTEMS DYNAMICS AND CONTROL
DYNAMICS
FLUID MECHANICS
THERMODYNAMICS
HEAT TRANSFER
ENGINEERNIG DESIGN PROCESS
MANUFACTURNIG
ENGINEERING REASONING AND PROBLEM SOLVING
EXPERIMENTATION AND KNOWLEDGE DISCOVERY
SYSTEM THINKING
PERSONAL SKILLS AND ATTRIBUTES
PROFESSIONAL SKILLS AND ATTITUDES
INDEPENDENT THINKING
TEAMWORK
COMUNICATIONS
EXTERNAL AND SOCIETAL CONTEXT
ENTERPRISE AND BUSINESS CONTEXT
MARKET CONTEXT
DEVELOPING AN IDEA
DESIGNING
TESTING
did not
else-
where
job
grad
school
MIT
ungd

underlying sciences

underlying mathematics

mechanics of solids

mechanical behavior of materials

systems dynamics and control

dynamics

fluid mechanics

thermodynamics

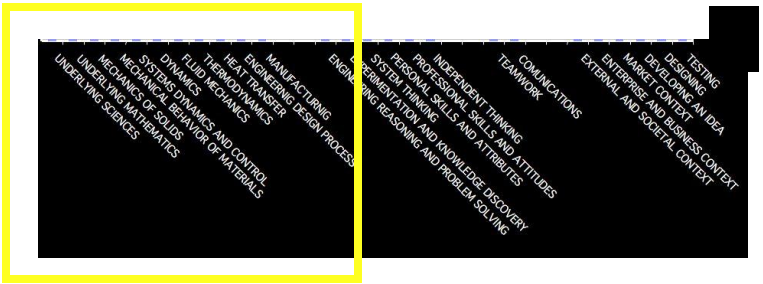
heat transfer

engineering design process

manufacturing

(Note: Analysis and Reductionist Thinking)

ME core



engineering reasoning and problem solving

experimentation and knowledge discovery

system thinking

personal skills and attributes

professional skills and attitudes

independent thinking

teamwork

communications

(Note: Synthesis and Integrative Thinking)

professional skills

testing

designing

developing an idea

market context

enterprise and business context

external and societal context

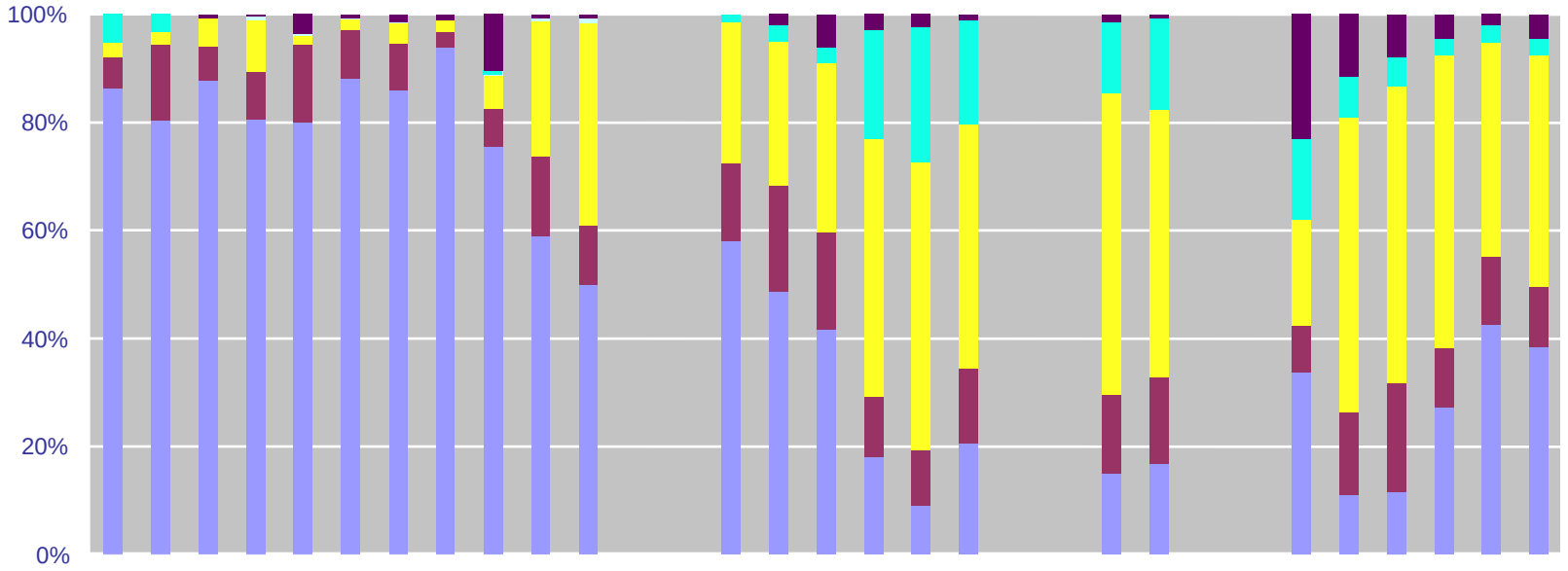
(Note: Entrepreneurial Thought and Action)

how

and

why

Source

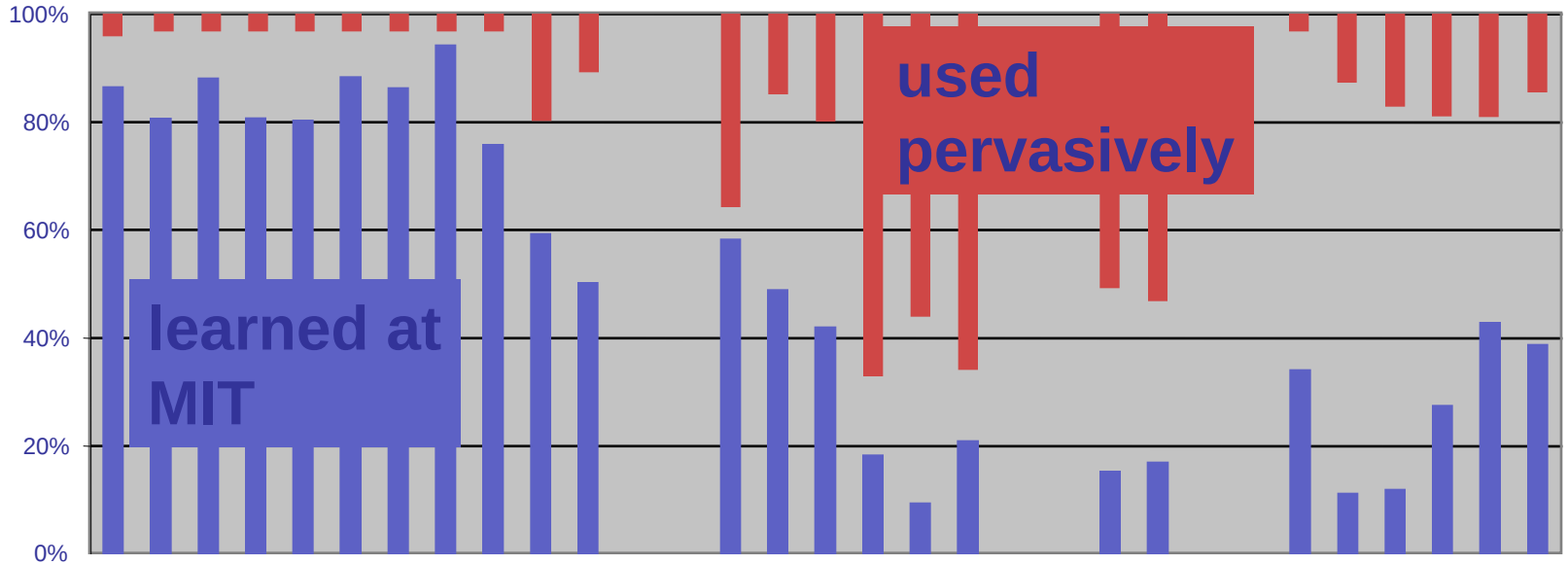


did not
else-where
job
grad school
MIT ungd

ME core

professional skills

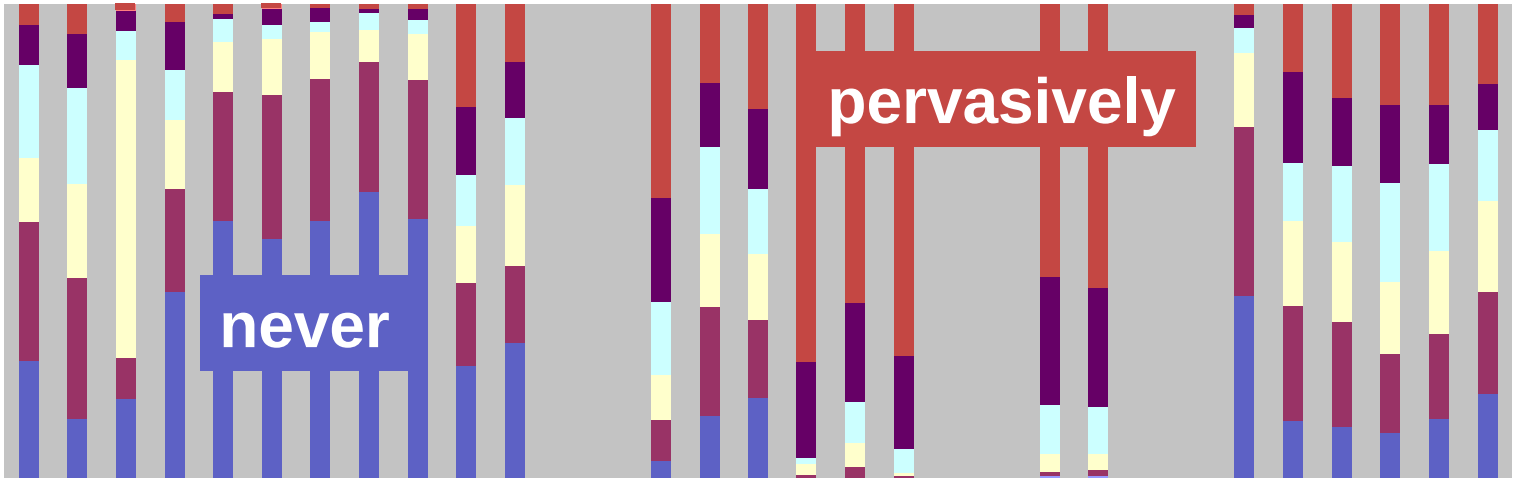
how and why



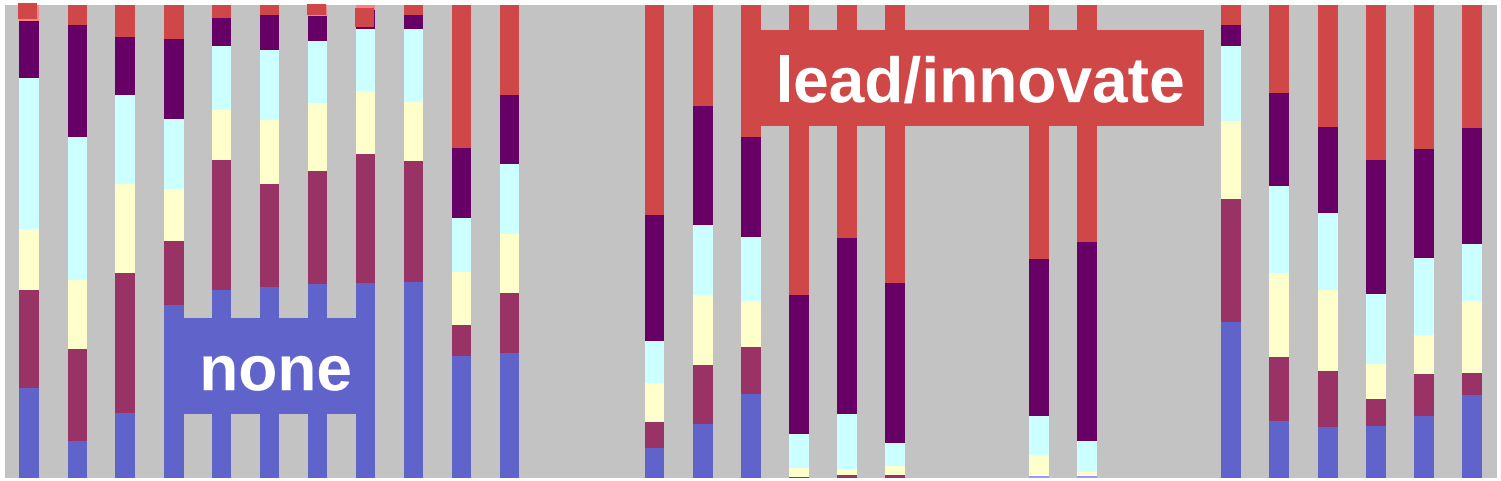
ME core

professional skills

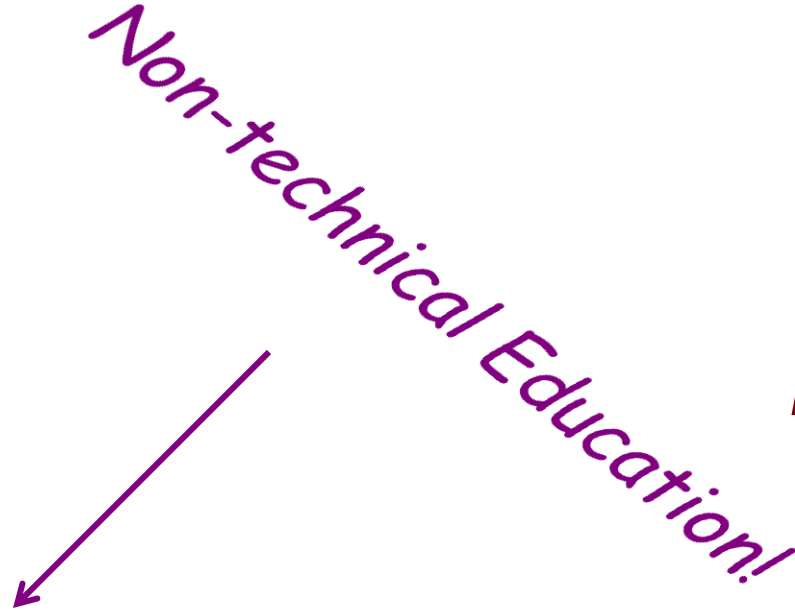
how and why



Frequency of use



Expected proficiency



not learned but pervasive

teamwork

communications

professional skills and attributes

personal skills and attributes

independent thinking

underlying sciences

underlying mathematics

dynamics

heat transfer

thermodynamics

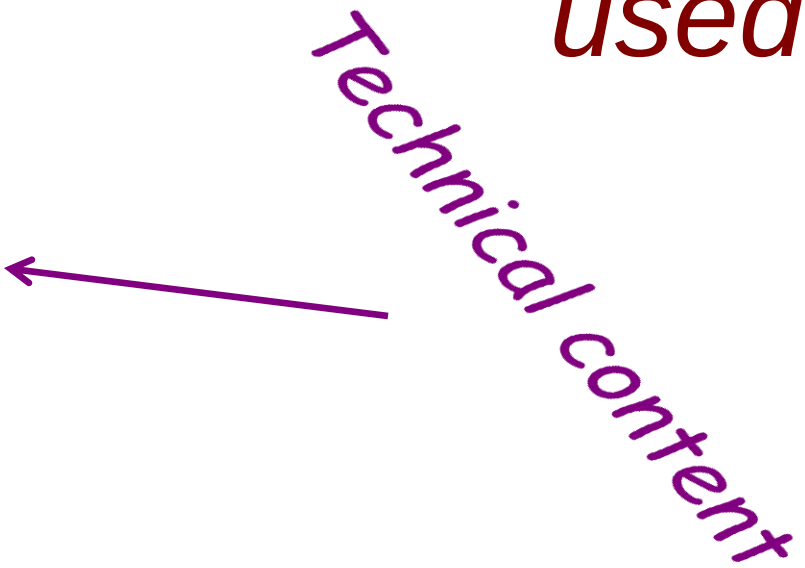
mechanics of solids

fluid mechanics

systems dynamics and control

mechanical behavior of materials

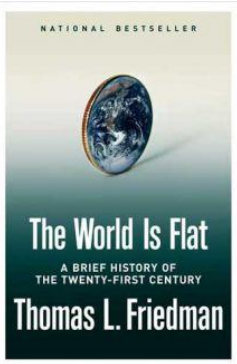
learned but seldom used

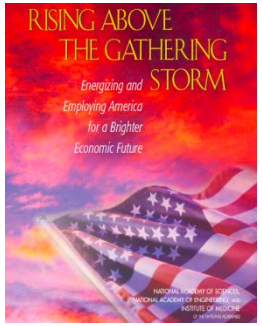


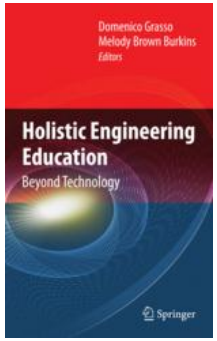
The Need for Change in Engineering Education

- Thomas L. Friedman, *The World is Flat: A Brief History of the Twenty-first Century*
- Council on Competitiveness, *National Innovation Initiative*
- National Academy of Engineering, *Rising Above the Gathering Storm*
- National Academy of Engineering, *Educating the Engineer of 2020*
- D. Grasso, M. Brown-Burkins, *Holistic Engineering Education: Beyond Technology* (Springer, 2010)

→ *Teamwork, communication, creativity, leadership, entrepreneurial thinking, ethical reasoning, global contextual analysis*

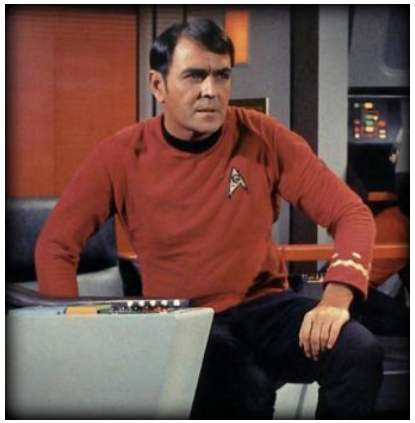






What Is An Engineer?

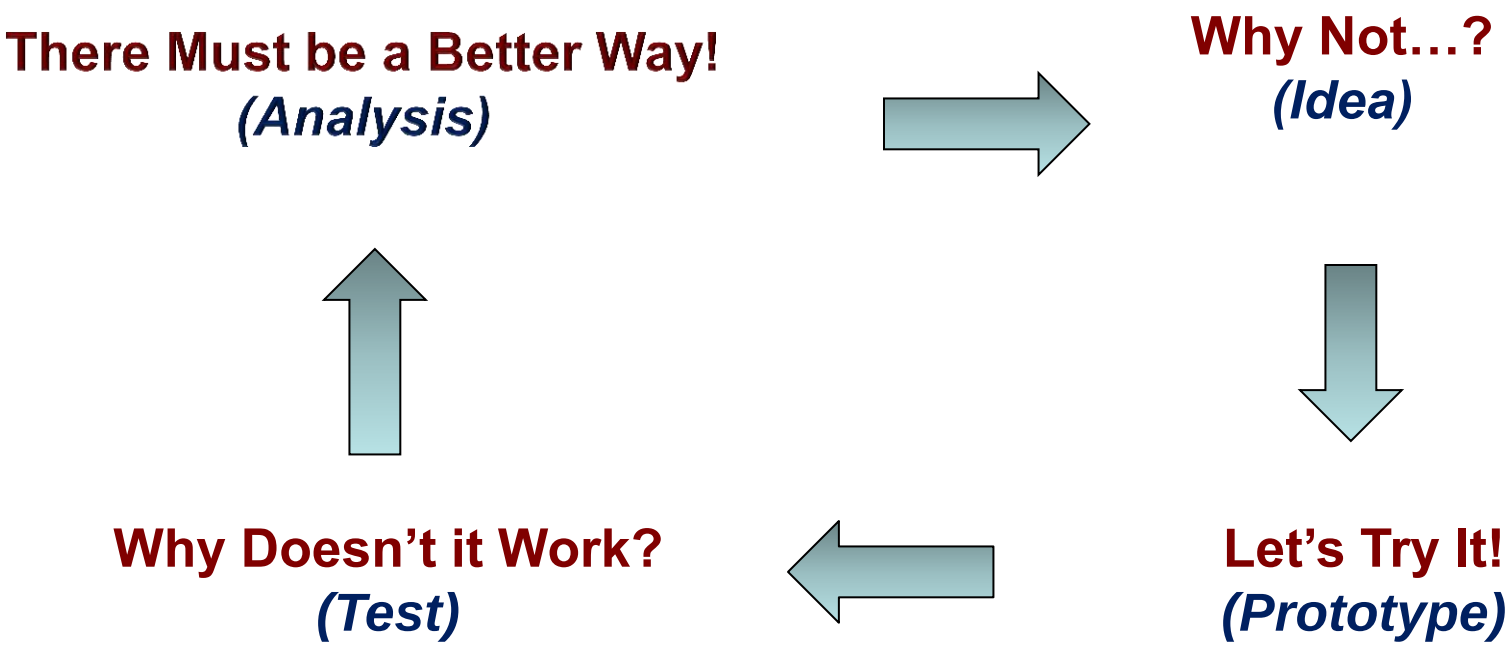
- *Applied Scientist*
- *noun: "a person who carries through an enterprise by skillful or artful contrivance," (Merriam-Webster Dictionary)*
- *Designer/Architect of a System, Process, or Device*
- *Project/Team Leader*
- *"To Engineer is to Make" (D. Chapman-Walsh)*
- *"An Engineer is a person who envisions what has never been, and does whatever it takes to make it happen"*



"Scotty"

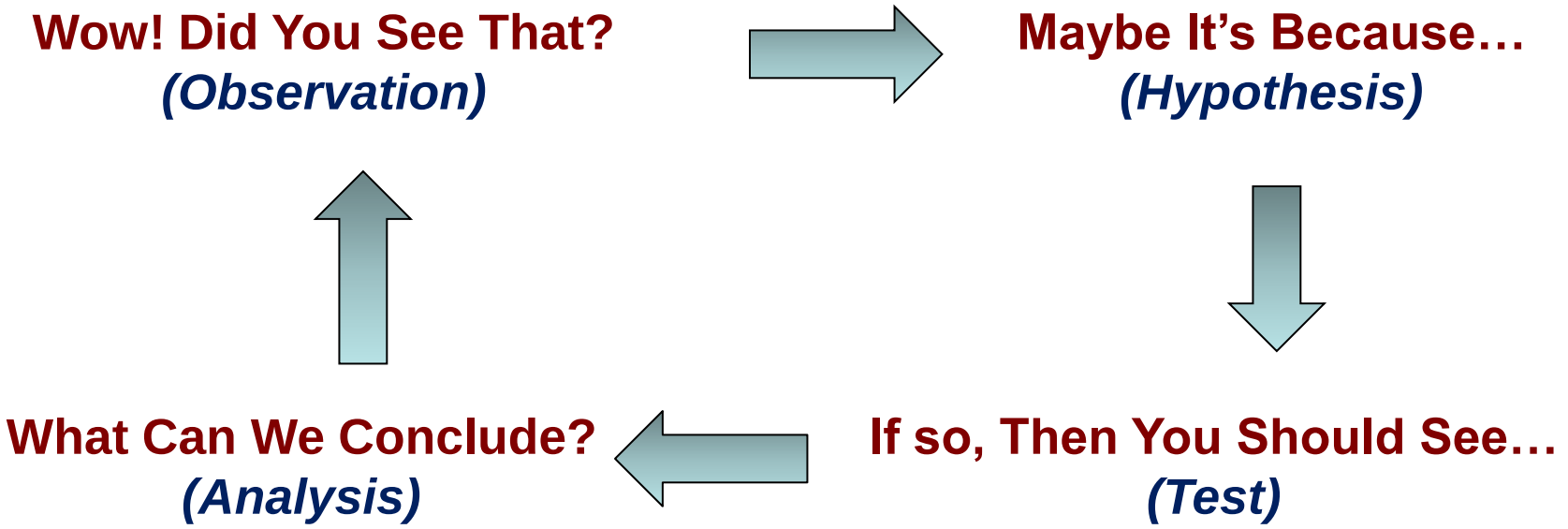
Engineering vs. Science

The Process of Engineering Design



Engineering is a Process, not a Body of Knowledge!

The Process of Scientific Discovery

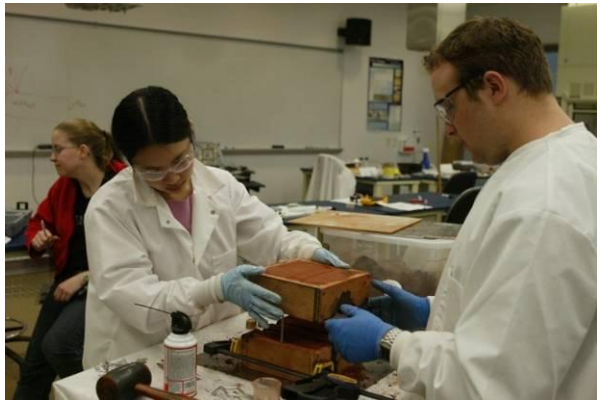


Science is also a Dynamic Process, not a collection of Static Facts!

3. A new model for engineering education

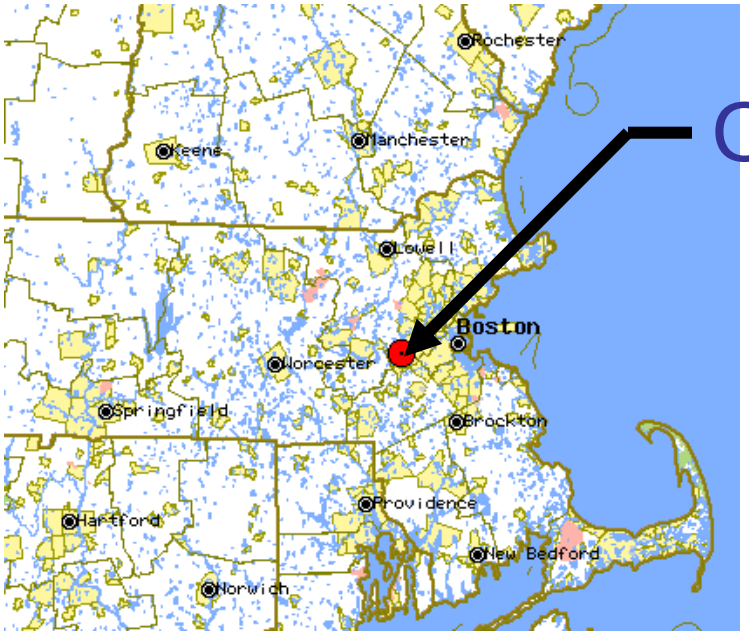
Olin College Overview

- Undergraduate residential engineering education
- Total enrollment of about 350
- Nearly 50% women
- BS degrees in ECE, ME, Engr only
- 9-to-1 student/faculty ratio
- Founded in 1997, first graduates in 2006
- 75 acres and 400,000+ sq. ft. new buildings
- Endowment > $1 million/student
- Research expenditures ~ $1 million/yr
- Adjacent to Babson College, Wellesley College
- No academic departments
- No tenure
- Low tuition
- Continuous improvement



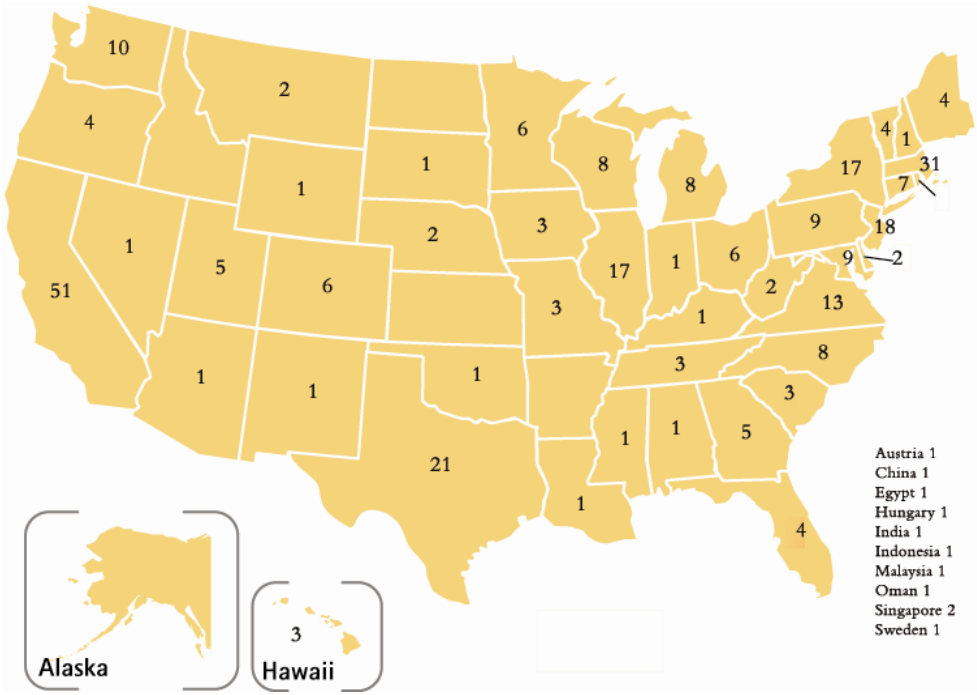
Olin College Campus
Needham, MA

Olin College Overview

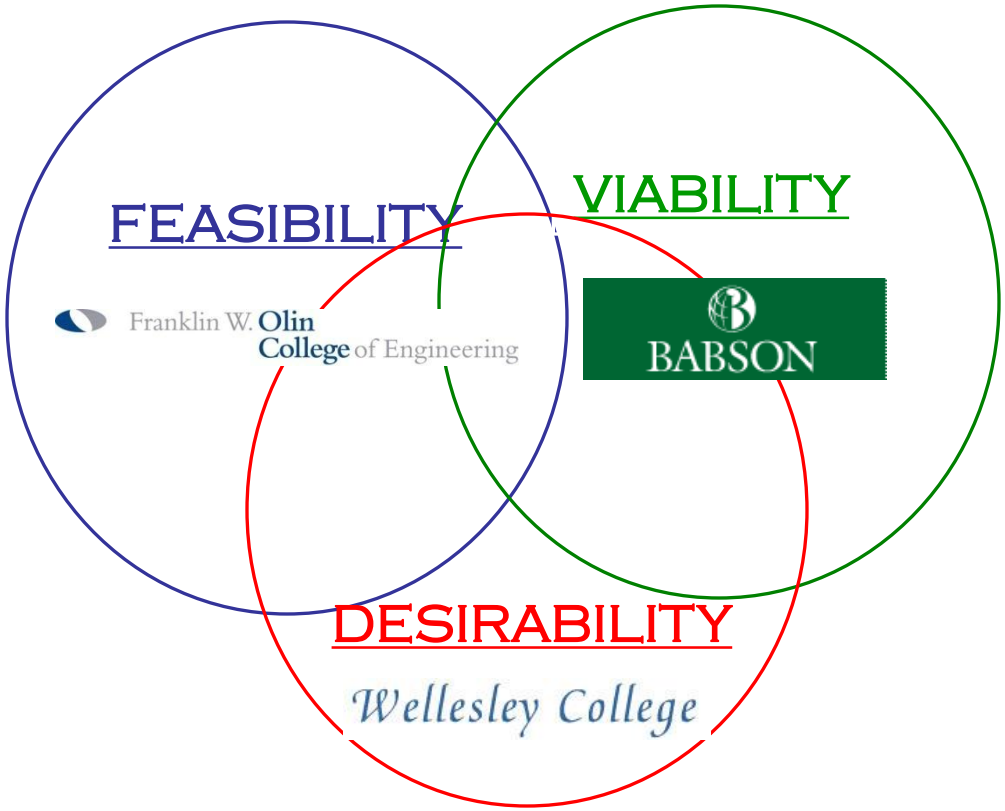


Olin College

Where Do Olin Students Come From?



Blurring Boundaries



Some Features of the Olin Curriculum

- ***Candidates' Weekend**: interviews required for admission*
- ***Extensive DESIGN** core required*
- *Multiple Team design projects required in 6+ semesters*
- ***SCOPE** senior project: corporate sponsored, year-long ($50k/project)*
- ***EXPO** at end of each semester: "stand and deliver"*
- ***Olin Self Study** self-directed independent research required for graduation*
- ***AHS/E! Capstone** project required for graduation*
- *Study Away in Junior year*
- *Summer internships: REU and corporate experience*
- *Business and entrepreneurship:*

  ***all students must start and run a business** for a semester*
- *Continuous improvement: **expiration date on curriculum every 7 years***

- *BUT, the **learning culture** is far more important than the curriculum!*

Reflections

Overall, Greatly Exceeded Our Expectations

Positives

- *very successful alumni*
- *intense student engagement*
- *increased motivation and autonomy*
- *strong leadership potential*
- *entrepreneurial "disease"*
- *very high levels of teamwork*
- *faculty commitment to lead change in education*
- *students ability to "stand and deliver," manage projects, and work with ill-structured problems*
- *strong engagement with Wellesley and Babson Colleges*

Negatives

- *concerns about balance: design vs. advanced theory, qualitative vs. quantitative design, etc.*
- *student interest grows beyond engineering to include leadership, policy, management, etc.*
- *alumni preference for small start-up companies*
- *assessment challenges: metrics?*
- *scalability?*
- *growing resistance to change(!)*

Student Engagement and Learning Outcomes

- *Educational research shows that the more students are enthusiastic and personally engaged in their studies, the more they learn, and the more they want to continue learning. (G. Kuh, E. Pascarella, A. Astin, etc.)*

- *National Survey of Student Engagement (Indiana University)*

  - *More than 500 universities and 500,000 students in the US*

  - *Five major areas:*

    1. *Level of Academic Challenge*
    2. *Active and Collaborative Learning*
    3. *Student-Faculty Interaction*
    4. *Enriching Educational Experiences*
    5. *Supportive Campus Environment*

→ ***Results for Olin College exceed 90%-ile level in 9 of 10 metrics***

First year Student Engagement (NSSE 2009)