Rethinking Engineering Education
From the Ground Up

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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
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 THE 20TH CENTURY

Welcome!
How many of the 20th century’s greatest achievements will you use today? Explore our list of the top 20 achievements that shaped a century and changed the world.

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. Nuclear Technologies
12. High-performance Materials
13. Space Travel and Exploration
14. Medical Advances
15. Information and Communication
16. Environmental Conservation
17. Transportation
18. Energy
19. Agriculture
20. Construction

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NAE Grand Challenges for the 21st Century

Security, Sustainability, Health, Joy of Living
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 21\textsuperscript{st} century
BUT,

Our traditional approach to higher education may be preventing us from producing innovators!
Feasibility
Engineering and Science

Viability
Business and Economics

Desirability
Psychology, Arts, Humanities, etc.

K-12 Education

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Feasibility: Engineering and Science
Viability: Business and Economics
Desirability: Psychology, Arts, Humanities, etc.
Feasibility

Viability

Desirability

All other subjects

No Uniformly Accepted Standards For Feasibility or Viability
Feasibility

Viability

Desirability

Innovation
Creativity & Cognition

YOUTUBE: Sir Ken Robinson (TED 2006)
CREATING INNOVATORS
The Making of Young People Who Will Change the World

TONY WAGNER

- All people have at least 7 “intelligences”
  - Linguistic
  - Logical/mathematical
  - Spatial
  - Bodily-kinesthetic
  - Musical
  - Interpersonal
  - Intrapersonal

- Academic Intelligence (IQ, SAT, etc.)
- Artistic Intelligence
- Persuasion, Management
<table>
<thead>
<tr>
<th>Traditional</th>
<th>New</th>
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<tbody>
<tr>
<td>Knowledge Transfer</td>
<td>Construct Knowledge</td>
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<tr>
<td>“Can’t Do”</td>
<td>“Can Do”</td>
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<tr>
<td>Follow Orders</td>
<td>Follow Your Passions</td>
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<tr>
<td>Learn in Class</td>
<td>Learn 24 x 7</td>
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<tr>
<td>Learn Alone</td>
<td>Learn in Teams</td>
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<tr>
<td>Problem-based</td>
<td>Design-based</td>
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“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)).


  YouTube:  Prof. Woodie Flowers on Education Reform
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
did not elsewhere 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)
engineering reasoning and problem solving

experimentation and knowledge discovery

system thinking

(Note: Synthesis and Integrative Thinking)

personal skills and attributes

professional skills and attitudes

independent thinking

professional skills

teamwork

communications
testing

designing

developing an idea

market context

enterprise and business context

external and societal context

(Note: Entrepreneurial Thought and Action)
Source

ME core
professional skills
how and why

did not elsewhere job grad school MIT ungd
learned at MIT

used pervasively

ME core

professional skills

how and why
Frequency of use:

- never

Expected proficiency:

- none

- lead/innovate

- pervasively
teamwork
communications
professional skills and attributes
personal skills and attributes
independent thinking

Non-technical Education!

not learned but pervasive
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*

• 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

There Must be a Better Way! (Analysis)
Why Not…? (Idea)

Why Doesn’t it Work? (Test)
Let’s Try It! (Prototype)

Engineering is a Process, not a Body of Knowledge!
The Process of Scientific Discovery

Wow! Did You See That? (Observation) → Maybe It’s Because… (Hypothesis)

What Can We Conclude? (Analysis) ⇄ If so, Then You Should See… (Test)

Science is also a Dynamic Process, not a collection of Static Facts!
3. A new model for engineering education
• 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

FEASIBILITY

VIABILITY

DESIRABILITY

Franklin W. Olin College of Engineering

BABSON

Wellesley College
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)

Mean Score (in Std Dev from Global Mean)

- Level of Academic Challenge
- Active and Collaborative Learning
- Student-Faculty Interaction
- Enriching Educational Experiences
- Supportive Campus Environment

Legend:
- Olin College
- Engineering
- Liberal Arts
- All Unvs.