Evolving to a New Normal in Engineering Education

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Outline

• Status of interest in Engineering in the US
  – Enrollment, Diversity, BS Degree Productivity, Salary
• What is Engineering? Definition frames how we educate and view our field
• History of Engineering Education
  – Engineering Education Paradigms and Forces of Change
• Evolving Learning Paradigms for Engineering Education
  – Ex. of Hands-on and Project Based Experiential Learning Experiences
• Who are we educating and what are their needs? Millennials/Gen Z
• Emergence of Online Engineering Education
  – MOOCs, virtual labs, tools
• Challenges facing the future of engineering education
• Summary of how Professional Societies can stay engaged
(Courtesy of ASEE)

US Enrollment in Engineering

- 1998
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015

704,818
US Engineering Enrollment Demographic Trends
(Courtesy of ASEE)
US Engineering Enrollment Demographic Percentages (Courtesy of ASEE)

![US Engineering Enrollment Demographic Percentages Diagram](chart_url)

- M UG Enroll: 76.9%
- F UG Enroll: 23.1%
- Af-Amer UG Enroll: 5.0%
- As-Amer UG Enroll: 5.3%
- Hispanic UG Enroll: 12.2%
- Nat Amer UG Enroll: 12.8%
- Cauc UG Enroll: 0.4%
- Two UG Enroll: 3.2%
- Unknown UG Enroll: 8.8%

**2005 Percentages**

**2015 Percentages**

SOURCE: US Census Bureau

**| Year | M UG | F UG | Af-Amer | As-Amer | Hispanic | Nat Amer | Cauc | Two | Unknown |
---|------|------|---------|---------|----------|----------|------|-----|---------|
| 2010 | 76.9 | 23.1 | 5.0     | 5.3     | 12.2     | 12.8     | 0.4 | 3.2 | 8.8     |
| 2015 |      |      |         |         |          |          |      |     |         |
US BS Degree Productivity/ Faculty Workload

Incredible period of growth
## Top 15 Majors by Salary-(2016/17)

*courtesy of www.payscale.com*

<table>
<thead>
<tr>
<th>Rank</th>
<th>Major</th>
<th>Degree Type</th>
<th>Early Career Pay</th>
<th>Mid-Career Pay</th>
<th>% High Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Petroleum Engineering</td>
<td>Bachelor's</td>
<td>$96,700</td>
<td>$172,000</td>
<td>56%</td>
</tr>
<tr>
<td>2</td>
<td>Systems Engineering</td>
<td>Bachelor's</td>
<td>$66,400</td>
<td>$121,000</td>
<td>50%</td>
</tr>
<tr>
<td>3 (tie)</td>
<td>Actuarial Science</td>
<td>Bachelor's</td>
<td>$60,800</td>
<td>$119,000</td>
<td>43%</td>
</tr>
<tr>
<td>3 (tie)</td>
<td>Chemical Engineering</td>
<td>Bachelor's</td>
<td>$69,800</td>
<td>$119,000</td>
<td>56%</td>
</tr>
<tr>
<td>5 (tie)</td>
<td>Computer Science (CS) &amp; Engineering</td>
<td>Bachelor's</td>
<td>$71,200</td>
<td>$116,000</td>
<td>45%</td>
</tr>
<tr>
<td>5 (tie)</td>
<td>Nuclear Engineering</td>
<td>Bachelor's</td>
<td>$68,500</td>
<td>$116,000</td>
<td>55%</td>
</tr>
<tr>
<td>7</td>
<td>Electronics &amp; Communications Engineering</td>
<td>Bachelor's</td>
<td>$68,000</td>
<td>$115,000</td>
<td>54%</td>
</tr>
<tr>
<td>8</td>
<td>Electrical &amp; Computer Engineering (ECE)</td>
<td>Bachelor's</td>
<td>$68,100</td>
<td>$114,000</td>
<td>49%</td>
</tr>
<tr>
<td>9 (tie)</td>
<td>Aeronautical Engineering</td>
<td>Bachelor's</td>
<td>$63,000</td>
<td>$113,000</td>
<td>61%</td>
</tr>
<tr>
<td>9 (tie)</td>
<td>Computer Engineering (CE)</td>
<td>Bachelor's</td>
<td>$69,600</td>
<td>$113,000</td>
<td>46%</td>
</tr>
<tr>
<td>11 (tie)</td>
<td>Computer Science (CS) &amp; Mathematics</td>
<td>Bachelor's</td>
<td>$63,500</td>
<td>$111,000</td>
<td>36%</td>
</tr>
<tr>
<td>11 (tie)</td>
<td>Physics &amp; Mathematics</td>
<td>Bachelor's</td>
<td>$56,200</td>
<td>$111,000</td>
<td>48%</td>
</tr>
<tr>
<td>13 (tie)</td>
<td>Applied Mathematics</td>
<td>Bachelor's</td>
<td>$56,100</td>
<td>$110,000</td>
<td>40%</td>
</tr>
<tr>
<td>13 (tie)</td>
<td>Electrical Engineering (EE)</td>
<td>Bachelor's</td>
<td>$67,000</td>
<td>$110,000</td>
<td>53%</td>
</tr>
<tr>
<td>15 (tie)</td>
<td>Electrical &amp; Electronics Engineering (EEE)</td>
<td>Bachelor's</td>
<td>$64,000</td>
<td>$108,000</td>
<td>61%</td>
</tr>
</tbody>
</table>
What is Engineering?

• ABET’s Definition
  – The profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgement to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind.

• Courtesy of NAE President C. Dan Mote (Changing the Conversation)
  – Definition for Engineering: “Engineers create solutions serving the welfare of humanity and the needs of society.”
  – Value Proposition (4 words)
    • Creation, Solutions, Humanity and Society
History of Engineering Education
(1st half of 19th Century)

• Engineering education in the U.S.: Three schools in the United States were the first to offer an engineering education:
  – 1802 Army established Corp of Engineers at Westpoint NY
  – 1817 – The U.S. Military Academy (West Point, NY)
    • First engineering curriculum modeled after Ecole Polytechnique in France
  – 1819 – An institution now known as Norwich University (Vermont), first with instruction in civil engineering
  – 1825 – Rensselaer Polytechnic Institute (New York)
History of Engineering Education
(2nd half of 19th Century)

- Engineering education expansion as part of Morrill Act of 1862, 1890: Justin Smith Morrill

125 to 160 years old
Engineering Education Paradigms over the last 100 years

- Pre-1950:
  - **Focus on Engineering Practice**: design according to codes and well-defined procedures; limited use of mathematics; many faculty with industrial experience and/or strong ties with industry

- 1950-1990:
  - **Focus Engineering Sciences**: fundamental understanding of phenomena; analysis; majority of faculty trained for academic research

- 1990-2010:
  - **Focus on Project Based Learning**, teamwork, communication, integration, design, manufacturing, continuous improvement; maintain analytic strength

- 2010 to Present:
  - **Focus on Active Learning**: experiential hands-on activities, teamwork, communication, design, creativity and innovation, project management, ethical reasoning, leadership, global contextual analysis. Incentivize instructional faculty. Encourage improvement in pedagogy and research into learning.
Need for Change in Engineering Education

Ensure US competitiveness in innovation and economic development
Forces Driving Change in Engineering Education

- Engineering college and departmental/program advisory boards
- Engineering professional societies including:
  - ASEE, IEEE, ASME, ASCE, AiCHE, AIAA, SHPE, NSBE, WIE, and many others
- National Academy of Engineering-(NAE)
  - Numerous studies demanding change
- National Science Foundation
  - Programs, workshops, studies, roadmaps
- Industry and Private Foundations
  - Kern, Ford, Bechtel, Chevron, Olin, Gates, many others
- The Accreditation Board for Engineering and Technology-(ABET)
  - Criteria, Outcomes, Processes
- Advances in Research, Facilities and Technology
  - Information technology, Online education and MOOCs, Flipped Classrooms, Makerspaces, open laboratories, Research in engineering education
Modern Engineering is Increasingly Complex
(slide from Charles Vest, then-president of NAE)

Smaller and Smaller
Faster and Faster
More and More Complex
Great Societal Importance

Larger and Larger
More and More Complex

- Engineering systems need social science, management, humanities, etc
- Convergence of natural sciences, medicine and engineering.

*Data Science and analytics*
Engaging Practice in Engineering Education

Multi-year, Vertically Integrated & Hands On
• Tying coursework to personal experience (*Science* 4 Dec 2009 p1410)
• Providing contextual and integrative activities (Cambridge-MIT Inst., 2007)
• Inculcating a “systems” perspective (Grasso et al.)

Unique Experiential:
• Hackathons
• Student Competitions/Challenge Prizes
• Service Learning
• Community Engagement

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**Diagram: Conceptual Framework for the Engineering Change Study**

- **Leadership and Business Management**
- **International Experiences**
- **Internships/Coops**
- **Innovation and Entrepreneurship**

- **Ph.D.**
- **M.S. Degree**
- **Senior Capstone**
- **2nd and 3rd Year Engineering Courses “Core”**
- **First Year Experience**
- **K-12 Education**
- **ABET Industry**
- **EIT, Professional Societies**
- **Maker Spaces**
- **Design Thinking**
- **Shops and Novel Classroom Environments**
Response to Active Hands-on learning for Maryland Engineering

Keystone Program:
- Focus on 1st and 2nd Yr Experiences
- Incentivize Best Instructional Faculty
- Improve Instructional Facilities
- Provide Sufficient Staff support
- Active Hands-on Learning
- Team Competition
- Use of UG Teaching Fellows
- Peer Mentoring
- Professional Engr. to review Designs

Collaborators:
- Texas A&M
- Univ. of Colorado, Boulder
- UC Irvine
- Univ. of Nevada, Reno
- Univ. of Arizona
- Truckee CC
- Montgomery CC

National 6-yr Average = 59%
Grand Challenges Scholars Program

- A global “grass-roots” program encouraged and supported by the NAE
  
  - Each school’s program includes curricular and extra-curricular activities designed to give students skills and experiences in five required areas: research related to a Grand Challenge, multidisciplinary experience, global dimension, entrepreneurship, service learning

- Over 36 US universities, 4 overseas
- 80 other have pledged to participate
Common Desires for Engineering Students

- Engineers as problem definers as well as problem solvers
- Flexible engineers better able to straddle uncertainty, risk, disciplines, cultures, ethics, evolving technologies, etc.
- Engineers prepared for creativity, innovation, business management, entrepreneurship and public policy leadership
- Stronger application skills without losing theoretical strength
Skills Building

Multi-dimensional Professionals

• Technical skills
• Communication skills
• Social skills
• Global awareness
• Leadership skills
• Intercultural competence (national, ethnic, religious, etc.)
Trends in Engineering Education

- **Experiential Learning**
  - Internships/Competitions/Challenge Prizes/Service/Venturing/NGOs

- **Inductive Learning**
  - PBL, Inquiry, Case-based, JIT, etc.

- **Expose Students to Design before fundamentals**
  - Real engineering, real early

- **Service Learning**
  - Many examples

- **Use of technology and flipped classrooms**
  - Encourage more discussion, reflection, leveraging online videos and learning tools

- **Deployment of engineering education research**

- **Concept Tests and Authentic Assessments**
Examples of Trends in Experiential Learning Activities

- Hackathon
- Student Competition
- Challenge Prize Project
- Student Run Incubator
- Engineering for Social Change
All-girl hackathons on the rise, the latest at the University of Maryland

If two is a coincidence and three is a trend, consider all-female, on-campus hackathons on the rise.

Now Technica, University of Maryland's first "all-ladies" hackathon — a collaborative, marathon session of computer programming — can be added to the list.

Open to all and scheduled for Nov. 7 and 8 at UM College Park, it's part of a growing slate of events that promote both gender equality, and female participation and interest in the often male-dominated tech sphere.

"Girls see the tech world as not so inviting," says Amritha Jayanti, a computer engineering major and Technica's founder, who participated in Bitcamp, a (co-ed) UMD hackathon, last year. "It seems intimidating at first."
Solar Decathlon 2017

UMD’s WaterShed Wins In 2011

WaterShed Will Continue to Serve as a “Living Classroom”

PEPCO PURCHASES THE UNIVERSITY’S WINNING SOLAR DECATHLON ENTRY FOR PUBLIC DISPLAY. MORE...
Hyperloop
StartupShell

• M3D
  – Founders: David Jones, BS in Computer Science and Michael Armani, PhD Bioengineering
  – Products: Consumer 3D Printers, affordable price (~$300), over 25,000 units sold
  – Year Launched: April 2014, Number of Employees = >70

• Food Recovery Network
  – Founders: Ben Simon, Mia Zavalij and Cam Pascual
  – 192 chapters 42 STATES. 1324680 POUNDS OF Food recovered
  – Year Launched: 2011
  – Feed the Hungry with Leftover Food from University Dining Hall
The course combines engineering with social change and philanthropy. Students work with a local community to develop an innovative solution and pitch their idea for Foundation Funding.

FRESHFARM Markets, the inaugural recipient of an Engineering for Social Change Grant, will use the award for their FoodPrints program, an educational program that integrates gardening, cooking and nutrition education into the curriculum at five DC Public Schools (DCPS).
Who are we educating today? Enter the Millennials/Gen Z...

- Each Generation has:
  - differing work ethics,
  - career expectations
  - management styles
  - social consciousness and connectedness
  - Knowledge of technology

- Significant change in these areas in the work place has been influenced by the entry of Millennials/Gen Z into the work force.
- They know what they want and they want it now!
- They want to work on projects that inspire and have a social impact.
Generational Continuum

Baby Boomers
- “I have worked hard and have been loyal. Keep and nurture my talent and I will stay”

Generation X
- “I am a single parent and I need flexibility to work from home otherwise I will fulfil my needs at another company”

/Milennials/Gen Z
- Digital Natives
- Always Online
- Socially Conscious
- Socially Connected

48 – 66 yrs
35 – 47 yrs
0 – 34 yrs
What types of students are we educating in the future?

- Digital Natives (since birth)
  - Savvy about online tools, blogs, social networks
- Always Online-AO students
- Want to make a difference in the world now with their knowledge/skills
- Ability to multi-task
- Comfortable with Ubiquitous Mobile Devices and Software Tools
Disruptive Innovation in Education

Yesterday’s Education
• Prof. lectures on Black or white Board
• Books
• Homework defined
• Quizes/Exams in class
• No Internet
• No email, or text
• No mobile devices

Today’s Education
• Some online lectures interactive with video
• Books supplemented with Lecture Notes
• Homework online
• Exams in classroom
• Use Clickers/tablets to engage students.
• Learning Management Systems to communicate and educate.

Tomorrow’s Education?
• All lectures online with blended learning.
• Automated Assessments of student performance.
• Flipped Classroom-Peer to peer, and instructional coaches.
• Experiential-Project Based Learning, Learn by doing
• MOOCs to enhance learning outcomes
## Learning in Transition

<table>
<thead>
<tr>
<th>Past Focus</th>
<th>The Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Learning objects</td>
<td>• Web learning applications</td>
</tr>
<tr>
<td>• Instructional design</td>
<td>• Learning activity design</td>
</tr>
<tr>
<td>• Self-paced learning (no interaction with others)</td>
<td>• <strong>Self-service</strong> guided learning and collaborative, social learning</td>
</tr>
<tr>
<td>• Content development</td>
<td>• Content capture</td>
</tr>
<tr>
<td>• CBT (computer based learning)</td>
<td>• ICT-Information and Communication Technologies for learning (Virtual/Online Labs)</td>
</tr>
<tr>
<td>• Learner tracking</td>
<td>• Formative automated assessment, learner profiles, e-portfolios</td>
</tr>
</tbody>
</table>

IMS Global Learning Consortium

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A. James Clark
School of Engineering
The Future of Learning will be characterized by
(Courtesy of Prof. Michael Auer)

- Open content
- Open technology
- Open knowledge

For all !!!

“By making the educational assets free, open and accessible, the open education movement is beginning to radically change the ecology and economics of education”.

(Toru Iiyoshi & M.S. Vijay Kumar, MIT)
Scaling the Learning Model
Infrastructure for a Massive Open Online Course

New Teaching Technologies and Social Models for Course Design

- **Relatively Common**
  - **Instructional Videos**
    - Faculty record high quality lectures and post online.
  - **Peer to Peer Academic Support**
    - Students post and answer questions via social media and message boards.
  - **Student Designed Tools**
    - Students/Instructor create online software learning tools to support course.
- **Relatively Scarce**
  - **Automated Assessment**
    - Student homework, quizzes, and exams graded by computer

**Data Analytics to monitor student behavior and performance**
Massive Open Online Courses - Is this time different?

1990s
- Several universities start distance based learning initiatives primarily for graduate education

2000s
- MIT Open courseware
- WebCT

2012-Today
- Udacity
- Coursera
- edX
- Khan Academy
- 2Tor
- Udemy
- Open HPI-Germany

Does the confluence of improving technologies in HD video, adaptive tutors, and fast connections; economic pressures regarding student debt and tuition; and social readiness to embrace distributed education with different relationships between students and instructors signal a change for Higher Education?
Possible Online Courses

- **Fundamental Math or Science**
- **Statics or Engineering Mechanics**
- **Mechanics of Materials**
- **Dynamics**
- **Engineering Design (May not be possible)**

- **Technology Entrepreneurship**
  - *Developing Innovative Ideas for Real Companies* offered via Coursera in Spring, Dr. James Green
  - *Surviving Disruptive Technologies*, Professor Hank Lucas
  - Over 30,000 students have already registered for course.

https://www.coursera.org/umd
Engineering Mechanics or Statics offered via Coursera

- **Introduction to Engineering Mechanics**
  - Dr. Wayne E. Whiteman, GaTech
  - [https://www.coursera.org/course/statics1](https://www.coursera.org/course/statics1)

- **Other Free Engineering Courses:**
Online laboratories (iLabs) are experimental facilities that can be accessed through the Internet, allowing students and educators to carry out experiments from anywhere at any time.

http://ilabcentral.org

- Global Online Laboratory Consortium-GOLC http://www.online-lab.org/

http://www.youtube.com/watch?v=9Kpz6LkT0Bk
Online UG Engineering ABET Accredited Programs

Electrical and Computer Engineering

• Arizona State University
  – First BS program in electrical engineering that is offered 100% online: http://asuonline.asu.edu/online-degree-programs

• SUNY-Oswego
  – http://beeol.ee.sunysb.edu/index.shtml

Are these ABET accredited online programs an anomaly?

How do professional societies contribute to this emerging trend?
Challenges for Online Engineering Education
(courtesy of Dean G. May at Ga Tech)

• **Pedagogy.** MOOCs offer a huge opportunity to investigate how to use technology to more effectively educate students and improve learning outcomes (Retention/Graduate Rates).

• **Scalability.** Optimal education requires interaction between student and teacher, and no professor can know 100,000 students in a MOOC.

• **Lab experience.** In fields such as engineering or medicine, hands-on laboratory experiences are crucial. (Would you want a doctor working for you without any hands-on training?)

• **Cheating.** Right now, cheating is virtually impossible to prevent in the online world.

• What is the role of Professional Societies as this new paradigm evolves?.

Opportunities for Collaboration w/ Professional Societies

- **Strategic Industry – University Collaborations**
  - Defining actual real world challenges that require innovative solutions in partnership with universities

- **Student-directed Hands-on Learning**
  - Annual competitions: SAE Car, others
  - Capstone design advice and design review

- **Competency-based Education**
  - Using technology to provide competency based training
    - Microsoft Course Series, Siemens, IBM, HP
    - What about society based course series?
Summary

• Status:
  – Engineering and CS jobs are in high demand.

• A new normal is evolving in engineering education
  – **Value Proposition: Creation, Solutions, Humanity, and Society**: greater emphasis on hands-on and experiential learning opportunities in context of current and future societal grand challenges.
  – Technology and active learning methods can enhance student outcomes.

• Professional societies play a critical role in
  – Connecting engineering education to real world practice and solutions
  – Serving as design team reviewers, mentors, advisors, lecturers/educators
  – Creating challenge/focused projects to advance technology and skills
  – Providing opportunities for international and service learning
  – Serving as ambassadors to the profession w/ respect to outreach to K-12
Final Thoughts…

• "The enterprise that does not innovate inevitably ages and declines. And in a period of rapid change such as the present…the decline will be fast."
  — Peter F. Drucker

• “Engineering Education must continue to evolve to a new normal to ensure US competitiveness in a rapidly changing world”
  — Darryll Pines
Questions?