International Symposium on "How to Foster Skilled Graduates?"

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Project Based Learning and Entrepreneurship in Engineering Education for the Third Industrial Revolution

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Abstract

Around the first industrial revolution (1760-1820) engineering education in the United States was born. Early engineering was mostly focused on Civil Engineering (CE) to train engineers for the design of nation's initial railway lines, bridges, harbors and roads. The second industrial revolution (1870-1914) witnessed the establishment of a huge number of universities prominently in science and engineering education, which gradually added the Mechanical Engineering (ME), Electrical Engineering (EE) and Chemical Engineering (ChE) to the traditional CE education. In the past couple of decades we are witnessing the third industrial revolution fueled by the growth of information networking technology and emergence of its applications in cyber physical systems and the Internet of things. In this era, engineering education is going through a "transformation" from the traditional specialty-focused curricula to "multi-disciplinary" curricula and "inter-disciplinary" research directed towards innovation and entrepreneurship. This trend leads to a need for more frequent re-examination and adjustments in the curriculum, as well as individual or small group based project-oriented delivery of educational content, and mechanisms for fostering inter-disciplinary cooperation in research programs. Based on a historical observation of evolution of engineering education in the US and four decades of experience in project based learning at the Worcester Polytechnic Institute, this presentation describes the role of project based learning and entrepreneurship in the transformation of education during the third industrial revolution.

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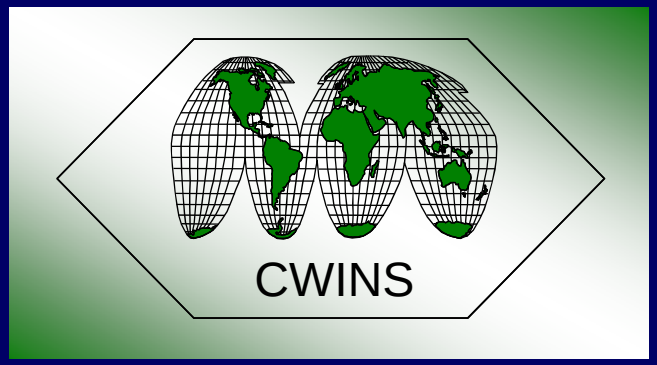

Project Based Learning in Engineering Education for the Third Industrial Revolution

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A SHORT HISTORY OF INNOVATIONS IN ENGINEERING EDUCATION

"History is who we are and why we are the way we are."

David McCullough

Pulitzer Prize Winner Author

"The only thing new in the world is the history you don't know.“

Harry S. Truman

"Any fool can make history, but it takes a genius to write it.“

Oscar Wilde

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"Economical Uncertainties" : Wars, Industrial Revolutions and Education

- During Economical Uncertainties in early 19th Century
  - American Revolutionary War (1775-1783)
  - Anglo-American War (1812-1815)
  - First industrial revolution (1760-1820)
  - Birth of the Engineering Education
- During Economical Uncertainties in early 20th Century
  - First Industrial Revolution (1860-1920)
  - American Civil War (1861-1865)
  - First World War (1914-1918)
  - Second world War (1939-1945)
  - Emergence of independent engineering, science and agricultural universities
- During Current Economical Uncertainties in early 21st Century
  - Third Industrial Revolution (1990-present)
  - Dis-integration of Soviet Union, War in the Middle East, Arab-Spring, Africa,….
  - Emergence of multi-disciplinary and inter-disciplinary engineering education and Project-Based Learning (PBL)

First Industrial Revolutions and the Birth of Engineering Education

- First industrial revolution (1760-1820)
  - Moving from wood to charcoal for energy and emergence of steam power resulted in an industrial revolution that impacted all aspects of life in particular in transportation (railroads, steam boats), textile (fast clothing machines) and metallurgy (iron for bridges)
- United States Military Academy at West Point (1802)
  - **Civil Engineering** becomes foundation of the curriculum in **1817**
  - Delivery was through self-study, homework and small classes
  - USMA graduates had major impact on construction the nation's initial railway lines, bridges, harbors and roads
- Rensselaer Polytechnic Institute (1824)
  - The first civilian and privately owned engineering school in the US
  - Founded as **Rensselaer School**, by **Stephen van Rensselaer** and **Amos Eaton**
  - Focused on “Civil Engineering,” designating engineering for civilian projects
  - Rensselaer was mostly attracting people with degrees from other institutions
  - Name was changed to Rensselaer Institute (1832) and to RPI in 1861 (2ed In Rev)

Second Industrial Revolution and the Emergence of Schools of Science, Technology and Agriculture

- Second Industrial Revolution (1860-1920)
  - Moving from coal to petroleum and emergence of combustion engine (cars), steel (long bridges), communication (telegraph, telephone and radio), electricity (light bulb) and mass production. These enabled industrial development in mining, machinery manufacturing, construction of canals and railroads.
- Because of this growth in the industry, US Government provided for the establishment of land-grant universities and a number of privately-endowed institutions were established[1]
  - 1858: Peter Cooper and the Cooper Union for Advancement in "Science and Art"
  - 1862: William Barton Rogers and MIT (Boston Tech)
  - 1865: John Boynton and WPI (Worcester Free Tech), Ezra Cornell and Cornell University, ..
  - 1870: Edwin Stevens and Stevens Institute of Technology
  - 1874: Chauncey Rose and Rose-Hulman Institute of Technology
  - 1885: Leland and Jane Stanford and Stanford University
  - 1891: William March Rice and Rice University
  - 1900: Andrew Carnegie and Carnegie-Melon University
- Engineering curriculum expanded from Civil Engineering into Mechanical Engineering, Electrical Engineering and Chemical Engineering

[1] Donald F. Berth, "The Second American Revolution : 1958-1900", WPI Journal, Spring 1991.

Third industrial Revolution and the Transformation in Engineering Education

- Third industrial revolution (1990-present?)
  - In the past couple of decades we are witnessing the third industrial revolution fueled by the growth of information networking technology and emergence of its applications in cyber physical systems (robotics), the Internet of things (sensor networks), renewable energy (solar, wind) and biomedical engineering (health care)
- Impacts on Engineering Education
  - In this era, engineering education is going through a “transformation” from the traditional specialty-focused curricula to “multi-disciplinary” curricula and “inter-disciplinary” research directed towards innovation and entrepreneurship.
- This trend lead to PBL and a need for
  - More frequent re-examination and adjustments in the curriculum
  - Individual or small group based project-oriented delivery of educational content
  - Mechanisms for fostering inter-disciplinary cooperation in research programs
  - Integration of humanities and social sciences with engineering
  - One of the pioneering experiences in the area is the WPI-Plan

WPI and "Lehr und Kunst"

- Third oldest Engineering School in US (RPI 1824, MIT 1862)
- Georgia Tech choses WPI as model over MIT (1885)
- First EE department building, Atwater Kent Laboratory (1906)
- Noble alumni before WWII
  - Atwater Kent (class of 1899), Robert Goddard (class of 1908)
  - Mei Yiqi (class of 1913), Harold Black (class of 1921), Kotaro Shimomura (Class of 1888)
- During WWII WPI was a Navy training camp (MIT initiated research laboratories)
- **1970: Revolutionary UG PBL program called "WPI-Plan"**
  - Projects: Humanities (Sufficiency), Social Science (IQP), Engineering (MQP)
  - "Competency Exam" rather than rigid course selection requirement
- Notable alumni after WWII:
  - Robert Stempel, (Class of 1955), Paul Alaire, (Class of 1960)
  - Dean Kamen, (dropped on 1976), Naveen Selvadurai, (class of 2002)

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Overview of the PBL: the "Plan"

- Curriculum structure and assessment
  - 4-terms, each 7-weeks, to allow **UG students** more flexibility to handle external projects
  - **Mandatory projects**, liberal curriculum and assessment with three grades: AD, AC, NR
  - A final oral "**Competency Exam**" to **assess** the overall preparation and depth
  - Began with **no additional resources**, **project centers** evolved and currently we are hiring **teaching faculty** to take the additional load burden
- Humanities Project (Sufficiency: 6-courses, mostly individual)
  - Students take **five thematically-related courses in humanities and arts** and conclude that with **a course-long independent study project**
  - Examples: research into contemporary music history, a student giving a flute recital
- Interactive Qualifying Project (IQP: 3-courses in groups of 1-4)
  - Relates **technology and science to society or human** needs by solving a problem
  - Examples: hoteling for patent examination process, fire safety in Green buildings
  - This project is often done off-campus through WPI's Global Perspective Program
- Major Qualifying Project (MQP: 3-courses in groups of 1-4)
  - MQP is similar to a **senior thesis**, students **doing independent research or design**
  - MQPs are often funded by either WPI or external corporations
  - Examples: Hybrid localization for Robotics, Using Robots for indoor WiFi mapping

WPI's International Project Centers

Society/Technology Projects

- Melbourne, Australia
- San Jose, Costa Rica
- Copenhagen, Denmark
- Venice, Italy
- Windhoek, Namibia
- Hong Kong, PRC
- Cape Town, South Africa
- Bangkok, Thailand
- London, UK
- Mandi, India
- Tirana, Albania
- Moscow, Russia

Senior Design/Research

- Nancy, France
- Alberta, Canada
- Kyoto, Japan
- Shanghai/Wuhan, China
- London, UK
- Budapest, Hungary

Humanities and Arts Projects

- Ifrane, Morocco
- London, UK

WPI Global Perspective Program

- 65% of students complete at least one project at an off-campus Project Center—most often the society-technology project
- About 50% do at least one project at an overseas Project Center
- Project Centers generally run for a single term with 24 students and 2 resident faculty advisors
- Projects are sponsored by local organizations: government, non-profit, NGOs, corporations, and research labs

WPI PBL impact on Faculty

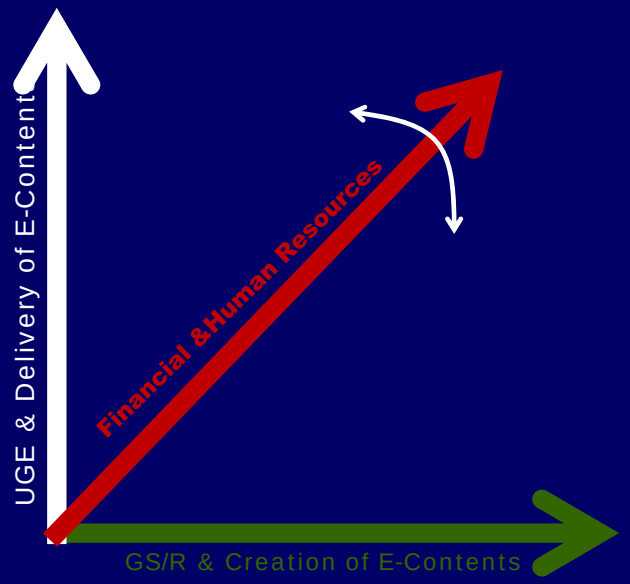
- Supervising projects
  - Faculty role moves from dispensing information, authority and expertise to responding to inquiries, coaching and being a facilitator
  - Supervisors per project: Sufficiency (1), IQP(2), MQP(1)
  - External projects adds staff of the companies as supervisors
- Faculty load:
  - WPI considers project supervision a part of normal load of a faculty
  - For 1-hpw meeting per project team (1-4 students), it compares with:
    - One graduate student thesis, or
    - A class with 3-9 students (20-50 is a normal class)
- Impact on faculty career
  - Faculty connects with the industry and real engineering problems
  - Faculty needs to gain new skills to handle the PBL delivery
  - UG projects responsibilities competes with research time of the faculty
- WPI established " Project Centers" and is hiring teaching faculty

WPI PBL and the Students

- New roles for the students
  - Students move away from: Dependence, Listening/Watching & *Gaining* Knowledge
  - Towards: Independence, Creating/Discovering and *Making* Knowledge
- Student's load and education
  - For each course we expect 12 hpw and a project load should be comparable
  - IQP and MQP are equivalent to 6-courses. Students continuing their education will have less preparation in background courses.
- Impact on students career
  - Opportunity to learn how to work in a group to solve a real problem
  - Opportunity for multi-disciplinary and cross-cultural experiences
  - Excellent opportunity to gain oral, written and presentation skills
  - Opportunity to be exposed to the work environment

Pros and Cons of PBL at WPI

- Core values
  - Exposure to real engineering problems
  - Individual or small group learning experience
  - Multi-disciplinary and cross-cultural opportunity
  - Strong impact on communications skills
  - Strong impact on career (judged by alumni)[2]
- Challenges
  - Administration is time consuming and expensive
  - Enforcing a uniform quality of education is difficult
  - Assessment of faculty load and student efforts is difficult
  - Students interested in research career need to take additional courses
  - Maintaining the quality research oriented faculty is an issue



[2] Arthur C Heinricher, Paula Quinn, Richard F. Vaz, Kent J Rissmiller, "Long-term Impacts of Project-Based Learning in Science and Engineering", American Society for Engineering Education, June 23-26, 2013.

How it may happen in other universities?

"If we knew what we were doing, it wouldn't be called [innovative] research, would it?"

Albert Einstein

(1879-1955)

"He wrote in three scripts:

The one that he wrote and only he could read

The one that he wrote and he and others could read

And the one that he wrote and neither he nor others could read

I write the third way!"

Jalal ad-Din Muhammad Rumi

(1207-1273 C.E.)

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