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Role of Project-Based Learning and Entrepreneurship in the Evolution of Engineering Education

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ABSTRACT

The communication revolution and ease of global connectivity have had a significant contribution to the industrial transformation from a short and long-term planned development to a more just-in-time design, development and production. Recent economic crises have impacted the rate of these transformations; however, the driving factors remain the technological changes in information and communication.

The transformation of industry has prompted a re-examination of the workforce development and educational system in the US and particularly in all STEM disciplines. Engineering education in US went through transformations after post American Revolution in 1860's and again after World War II in 1950's. The recent industrial transformation requires another major change in engineering education. Engineering programs are going through “transformations” from their traditional focused curriculum. These changes need to produce “multi-disciplinary”, project-based learning as well as “inter-disciplinary” and “multi-disciplinary” innovation and entrepreneurship in the curriculum and its delivery. These approaches require collaborative teaching and learning and the ability to form inter-disciplinary cooperation in research programs. A successful transformation of this form for engineering programs demand entrepreneurship and visionary talents to adapt to these frequent changes and industrial experiences to direct the transformation towards emerging inter-disciplinary industries such as cyber physical systems and digital manufacturing. These transformations need to address the spectrum of education and workforce development for pre-college to undergraduate, graduate and continuing education.

INTRODUCTION

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 project-oriented delivery of educational content, and mechanisms for fostering inter-disciplinary cooperation in research programs. A successful transformation of engineering education demands entrepreneurial and visionary talents to adapt to these rapidly-unfolding changes and to the shifting industrial world in order to direct the transformation towards emerging inter-disciplinary industries such as cyber-physical systems. The need for this transformation creates an opportunity for those universities that lead the transformation to enhance their ranking and reputation among their peer institutions. Based on a historical observation of evolution of engineering education in the US, this paper describes a vision for the future of engineering education and proposes a transformation path for programs in the US.

Webster’s dictionary defines an entrepreneur as a “person who organizes and manages a business and assumes the risk for the sake of a profit”. Under this definition, an individual who sets up a movable stall to sell gourmet coffee on the side-walk of a busy university campus is, probably a very successful, entrepreneur. So are many much more recognized entrepreneurs such as Bill Gates or the late Steve Jobs. The word, entrepreneur, dates back to the 13^{th} century and was made popular by the French economist, Jean Baptiste Say in the early 1800s. The definition has not changed for several hundred years. Business schools have been “teaching” entrepreneurship by covering subject matters such as; marketing, business planning, revenue management, business risk management, return on investment and alike for decades. These subjects have been often drastically transformed in response to the changing nature of the global business. However, the core of entrepreneurship (which may have to also be learned and not taught) depends on understanding the market place and consumer needs and that can range from local all the way to global.

While the impact of technology on business has been studied continuously, it has been in terms of how markets can expand. In fact, we have seen an explosion in products related to the invention of smart phones and often directly attributed to the core innovation of the interactive touch screen capability. Markets have been developed when the consumer “need” was not perceived or predicted. It is this new paradigm of innovations that are inspiring uses previously not thought about that captures the imagination of the current generation. It is the ease of transfer of information and knowledge, made possible by the communication revolution that has triggered a tremendous acceleration of ideas and innovations.

To meet these accelerated demands from the market place, industry has been coming to the universities asking for new skill sets. These demands should prompts the necessity for a renewal and transformation of education in general, and engineering education in specific, to capture the unbound energy of new ideas and thoughts into a disciplined and technically grounded approach aided by business tools to produce "innovative technological entrepreneurs". Analytical thinking, creativity, and the innovation process, which are the driving forces for the technological entrepreneurs, must be at the core of engineering education transformation.

Overview of Project Based Education and Entrepreneurship

Multi-disciplinary project-based learning offer challenges for engineering education due to pressures to contain required credits for graduation and entrenched discipline approaches to capstone final projects. The industry is increasingly is demanding team-based projects involving "inter-disciplinary" and "multi-disciplinary" experiential learning. Many universities have found that promoting innovation and entrepreneurship in the curriculum provides valuable experience for the students, but inherently exposes them to inter- and multi-disciplinary problem solving.

Innovation and entrepreneurship in engineering curriculum is anchored in critical thinking, technical foundation and recognition of consumer discovery. A successful delivery of this type of education is based on recognizing that innovation is at its core aided by an understanding of the business environment. To truly educate engineering entrepreneurs, there has to be recognition of the type of entrepreneurs we need in engineering. Lumsdaine and Binks address this issue in their paper and described it effectively as shown in Figure 1. Adaptation can easily be mistaken with innovation. To recognize true innovation, one must understand that innovation is not taught, but learned. This understanding points to the success that project-based-learning and experiential learning has shown to have and the student's appreciation of these approaches as opposed to traditional classroom teaching.

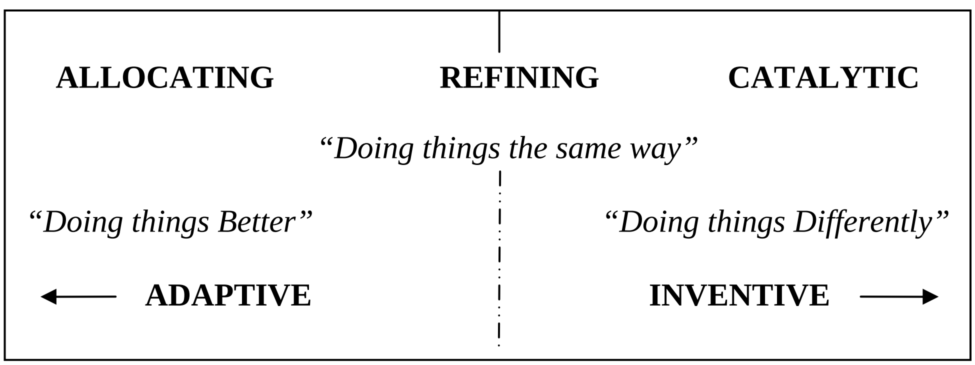

Figure 1 - Types of Entrepreneurs (Lumsdaine and Binks, 2003).

Economic Uncertainties and the Need for Transformations in Engineering Education

The transformation of industry has prompted a re-examination of the workforce development and educational system in the US, particularly in all STEM disciplines. Engineering education in the US went through transformations 1860s, during and following in the Civil War, and again in 1950's following World War II. In response to the recent transformation in the industrial design and development model, engineering programs are evolving away from their traditional specialty-focused curricula. These changes need to lead toward “multi-disciplinary”, project-based learning as well as “inter-disciplinary” and “multi-disciplinary” innovation and entrepreneurship in the engineering curriculum and its delivery. These approaches require collaborative teaching and learning and effective mechanisms to foster inter-disciplinary cooperation in research programs. A successful transformation of this form for engineering programs demand entrepreneurial and visionary talents to adapt to these frequent changes and industrial experiences to direct the transformation towards emerging inter-disciplinary industries such as cyber physical systems and digital manufacturing. These transformations need to address the spectrum of education and workforce development from pre-college through undergraduate, graduate and continuing education.

A brief historical review of education in science and engineering

"History is who we are and why we are the way we are." David McCullough, Pulitzer Prize Winner Author.

Early engineering was Civil Engineering (CE) and Mechanical Engineering (ME), essentially technology training, seen then as bringing the traditional master-apprentice model into the classroom. The US Military Academy (USMA) at West Point was the first engineering school in the US, established in 1802, to train cadets in artillery and engineering studies. West Point was originally a garrison and then had been a training center for military cadets since the war of independence. In 1812 during the war with British, the US congress authorized a more formal education at USMA. The first curriculum was developed under Colonel Sylvanus Thayer in 1817 and USMA produced graduates who gained recognition for engineering the bulk of the nation's initial railway lines, bridges, harbors and roads [Wikipedia, wiki/United_States_Military_Academy, 2014]. The first civilian and privately owned engineering school in the US was Rensselaer School, founded by Stephen van Rensselaer and Amos Eaton in 1824, which was focused on “Civil Engineering,” a newly-coined name chosen to designate engineering for civilian projects. In 1832 the name was changed to Rensselaer Institute and in 1861 to Rensselaer Polytechnic Institute (RPI). At first, Rensselaer was primarily a graduate school attracting people already holding degrees from other institutions [Wikipedia, wiki/Rensselaer_Polytechnic_Institute, 2014].

Major strides in the emergence of science, engineering, and agricultural universities, however, began around the time of the US Civil War (1861-1865). In this period industrial development had begun in mining, machinery manufacturing, and construction of canals and railroads; consequently through the Morrill Land-Grant Acts of 1862 and 1890, the US Government provided for the establishment of land-grant colleges [Wikipedia, wiki/Morrill_Land-Grant_Acts, 2014]. After the Civil War the US directed its attention to building industry and public infrastructure – roads, bridges, shipping ports, municipal water and waste systems, *etc*, which created a need for people trained in science and engineering. This era witnessed the establishment of a number of privately-endowed institutions that still to this day figure prominently in science and engineering education [Berth, 1991], among which we have:

- 1858: Peter Cooper and the Cooper Union for Advancement in "Science and Art"
- 1862: William Barton Roger and MIT to teach fundamentals of sciences for engineering
- 1865:
  - John Boynton and WPI to combine the theory and practice
  - Ezra Cornell and Cornell University, a land grant university for innovation in science and engineering
  - Asa Packer and Lehigh University to combine a liberal and scientific education
- 1870: Edwin Stevens and Stevens Institute of Technology, dedicated to Mechanical Engineering
- 1874: Chauncey Rose and Rose-Hulman Institute of Technology to educate engineers
- 1885: Leland and Jane Stanford and Stanford University to become one of the prominent engineering schools of the modern time
- 1891: William March Rice and Rice University to turn the fortune gained from engineering endowers to education
- 1900: Andrew Carnegie and Carnegie-Melon University to create a vocational training school in Pittsburgh

Into the early years of the 20th century, engineering education followed its initial format, technology training, with engineering specialties beginning to evolve, but still without a strong base in science. World War I was one pivotal point in the evolution of engineering education. The US was cut off from accessing German science and technology. This forced US engineering schools to put more focus on science, especially Chemistry and Chemical Engineering, education, whose origins in the US had been strongly influenced by German universities [Peppas, 1989]. This seems to be the first "wake-up call" to incorporate more science and research into US engineering education [Geiger, 1986].

The years of the Great Depression (1929-1941) saw a dearth of investment in the country's industrial infrastructure and thus represented a stagnant point in engineering education. The US was in an isolationist mood, and military preparedness was at an all-time low.

World War II was another pivotal point in the evolution of US engineering education. The country was totally unprepared for war, and the nation had to re-mobilize rapidly. Japan and Germany had built up enormous military capability and the US was under grave threat. The US Government realized that our industries and technologies had been neglected, and there had been little or no cooperation between the scientific community and the military [Stewart, 1948]. In the months prior to the US entry into the war, President Roosevelt established the National Defense Research Committee (NDRC), chaired by Dr. Vannevar Bush, former Vice President and Dean of Engineering at MIT. As the US entered the war, training programs were rapidly put into place in engineering schools and many other colleges and universities, *e.g.*, Navy V-12 programs at Cornell, MIT, RPI and WPI. As WWII drew to a close, Vannevar Bush began articulating the idea of government investment in science, and this led to the establishment of the National Science Foundation (NSF) in 1950. This launched a new era in science and engineering education, with an emphasis on science, funded with public dollars [Zachary, 1997].

During the Vietnam War era (1956-1975) warfare had a different kind of effect on science and engineering education in the US. The US Government's effort to provide "both guns and butter" depleted the previous sources of funding for science, while the anti-war sentiment turned much of the country against science and technology [Reich, 1995].. By the end of the 1960s, engineering schools were experiencing a severe reduction in numbers of applicants, and some schools were in difficult financial circumstances. This era brought about a re-examination of science and engineering education, goals and approaches.

DISCUSSION

Current Need for Transformation of Engineering Education

Engineering and science education is essential for an industrialized economy. Individuals with technical knowledge and expertise are needed to build infrastructure and meet the demands for design and production of consumer goods in such economies. The history of the world has witnessed periods of "economic growth" and periods of "economic uncertainties". Most of the widely spread wars as well as S&E educational transformations have occurred around these "economic uncertainties". As we saw in the last section, engineering education in the US was born in early 1800's, a few decades after the American Revolutionary War (1775 - 1783) and when the Industrial Revolution was just beginning. This transformation in education from traditional liberal art to science and in particular engineering facilitated the growth of civil engineering infrastructure.

During the time of economic uncertainties surrounding the Civil War (1861-1865), a war between the emerging industrialized economy of the North and the agricultural economy of the South, the country witnessed another transformation in science and engineering education. Numerous independent engineering and science universities and land-grant universities in agriculture, science and engineering were established to seed the prosperity of the US economy in the second half of the 20th century. Huge number of graduates from these universities filled and then overcame the gap between the economy of the US and that of Western European countries, where the industrial revolution had begun.

After the WWI (1914-18) and during the Economic Uncertainties of the Great Depression (1930s to mid-1940s) and subsequent WWII (1939-1945) we saw another transformation in S&E education. During WWII a number of innovative and scientific technologies such as rocketry, airplanes, atomic energy, radar, and radio communications played a decisive role. Research in academic institutions played a major role in development of these science-based technologies. As a result, universities which contributed in this research secured prominent and lasting stature in the field of US higher education.

During the Current Economic Uncertainties in the early 21st Century, we observe a number of conflicts across the world, from the Arab Spring, to Afghanistan, Iraq, Syria, and more recently, Ukraine. At the same time, in our own country, we see an increasingly rapid pace of change in business and industry, and the traditional patterns of specialty-focused career preparation is giving way to a new pattern of "individualized careers". Thus we see a shift in Science and Engineering education toward multi-disciplinary and inter-disciplinary research and entrepreneurship, and re-emergence of PBL to tailor the science and engineering education towards individual and small groups.

In the past few decades, all science and engineering schools have focused on a dynamic program to expand their research programs and national rankings by hiring research competitive faculty and establishing engineering research centers. The next opportunity for the growth of the science and engineering universities lies in establishing programs at universities to establish models for the "transformation" of the S&E educational identity. In order to lead this transformation, such model programs have to project the innovative and entrepreneurial approaches demanded by the industry, and increasingly, the students. In a paper published by Duval-Coueil and Wheadon (2014), they concluded that "In an increasingly turbulent job market, engineering students are seeking ways to differentiate themselves and gain skills that will make them valuable to companies and society at large. In many cases, [such] students are involved in entrepreneurship programs and activities."

Developing model programs can be aided by a number of actions, some leveraging existing approaches and some by implementing transformational programs and approaches.

- Promote establishment of multi-disciplinary engineering research centers. A successful program should nurture multi-disciplinary ERCs focused on current research topics in emerging areas such as cyber technologies, health care delivery and robotics and ensure they are engaged with students at all levels.
- Organize high profile international events focusing on the future of S&E education. These are very important initiatives for the global economy and can bring considerable increase in the reputation of a university program as a leader in multi-disciplinary research and scholarship.
- Promote curriculum transformation towards multi-disciplinary and inter-disciplinary graduate education and entrepreneurship and encourage multi-disciplinary faculty hiring. This will attract more internal and external resources for PBL.
- Effectively address student ownership of the Intellectual Property which is a key enabler to engage students in innovative project-based-learning.

Encourage integration of entrepreneurship by creating a bridge among science and engineering colleges and the business colleges. To ensure a successful and leading multi-disciplinary program, programs need to increase the entrepreneurship activities of the S&E by encouraging and facilitating faculty contacts with the venture capital (VC) community and government agencies engaged in nurturing startup companies and establish relationship with Government sponsored SBIR/STTR companies, which can be instrumental in helping other faculty to direct the results of their research toward entrepreneurship needed for successful multi-disciplinary and inter-disciplinary research and scholarship programs of the future.

Challenges in Project-Based Learning (PBL) and Integration of Entrepreneurship

Two of the challenging issues for PBL are the assessment of the learning outcomes and the evaluation of resources that are needed for its implementation.

An overview of an evaluation study of the impact of the PBL undergraduate program for students who graduated from Worcester Polytechnic Institute (WPI) in science and engineering between 1974 and 2011 is reported in [4]. WPI has featured a project-based curriculum since the early 1970s. This study focused on alumni of the school over a span of almost 40 years to examine the attributes of the PBL on the career of the alumni of the school in different points of their career and at different socio-economical settings of the country. This interesting study is in contrast with other studies of the impact of PBL on student engagement, student retention, and student learning. The results of this study showed that PBL had long-term positive impacts on alumni in terms of professional skills, world views, and personal lives [4]. The study also concluded that the PBL had stronger positive impacts on (1) engineering majors when compared to non-engineering majors and (2) on alumni who completed off-campus projects when compared with those who completed on-campus projects. These findings provide a unique perspective on the long-term impacts of PBL.

Financial and human resources in any academic institution have their own limitations. As shown in Figure 2, these resources are used for research and creation of knowledge that is used as the education contents (E-contents) for graduate education. Undergraduate education, however, mostly relies on the delivery of existing E-contents. If an educational institution or a professor leaves more emphasis on delivery of the E-contents, since resources are fixed, creation of E-contents will receive fewer resources. PBL creates a need for individual training that demands more of resources to enrich the delivery of content (see the Figure 2); this competes with the time and resources needed for the generation of content and faculty time needed for research. The current trend of expectation and assessments of the effectiveness of the faculty in all universities is mostly focused on ability to attract funding and the impact of the results of faculty research. Spending more time and other resources for delivery of content is in conflict with that objective. Therefore, structuring of a cost efficient model for PBL to allow quality E-content delivery and maintain with high level of expectations on research is a significant challenge for Science and Engineering universities.

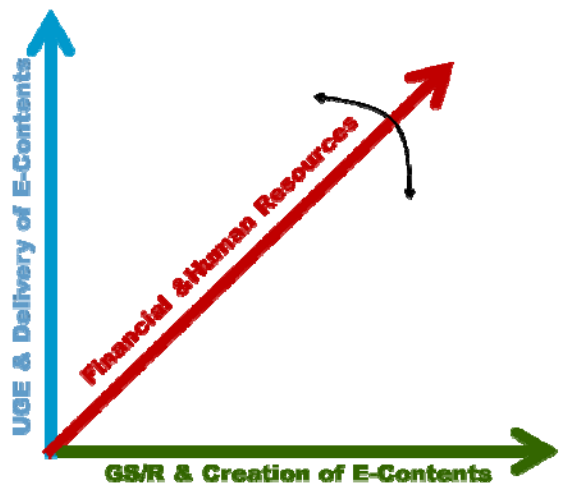

Figure 2 - Financial and human resources are fixed, but they map onto two orthogonal axis, graduate studies and research which creates the educational contents and undergraduate education which mostly befits from the delivery of contents.

Generation and delivery of E-contents present a significant resource constrain. Some universities resort to hiring teaching faculty to provide release time for research oriented faculty. In the long term, this approach can partition the faculty creating a challenge for administration to manage the faculty using two sets of standards. Integration of graduate students as teaching assistant (TA) to provide the additional resources needed for the delivery of contents of the PBL may offer a more reasonable solution. This approach has been tried in general, but using PBL to integrate innovation and entrepreneurship into the curriculum will need validation. TAs are normally used to facilitate the delivery of contents by organizing help sessions and grading the papers, if we want to engage them in BPL they have to work on creating the content for the projects that they may not have adequate experience in. It is possible to create a hierarchy with a professor on top and PhD students working with the MS students while MS students work with the BS students. Educational systems have evolved over a long period of time, new experiences such as these requires experimentation and assessment periods and resources to allow the experiments. We believe this challenge is open and those who find the practical solution for the problem will receive recognition in engineering education.

In most universities the current approach to fostering entrepreneurship is to promote the idea through the business schools. In a PBL environment, one can form teams of science and engineering students with business school students to ensure development of business plan prior to implementation of a project. The challenge here is the assessment of the quality of entrepreneurship, which is not in the specialty domains of the typical faculty members and for that one may need to engage members of the Venture Capital (VC) community or business executives who are willing to participate. This is again a relatively new concept in education that calls for experimentation and assessment before it can be adopted for long term implementation. NSF I-Corps-L is a pilot program that is experimenting with this approach in the learning (L) domain.

CONCLUSIONS

Duval-Couetil (2013) states that "*Entrepreneurship education programs are increasingly being established and expanded in an effort to equip students with the knowledge and competency necessary to create economic value and jobs.*" The key issue for engineering education is to ensure that the business model of entrepreneurship does not become the dominant component of the program. Such approaches often results in technical minded students to shy away or not embrace the program. Emphasize on the technical learning, innovative problem solving integrated with proven business models for understanding market forces and entrepreneurship principles may allow for success. As Duval-Couetil (2013) points out the assumption of positive outcomes for the students does not guarantee the extent and nature of these outcomes which have to yet be quantified. The foundation of a transformation approach to new approaches in engineering education should be in anchoring programs in inter- and multi-disciplinary technical innovation with appropriate integration of entrepreneurial skills and principles.

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Kaveh Pahlavan is a Professor of ECE, a Professor of CS, and Director of the Center for Wireless Information Network Studies, Worcester Polytechnic Institute, Worcester, MA. He is also the chief technical advisor of Skyhook Wireless, Boston, MA. He has had long term cooperation with the University of Oulu and Nokia in Finland. His current area of research is design of cyber physical systems for hybrid localization of the video capsule endoscope, his research background is in indoor geolocation and wireless local area networks. He has contributed to numerous seminal visionary publications as well as technical books, papers and patents. He is the founding Editor-in-Chief of the International Journal on Wireless Information Networks and a member of the advisory board of the IEEE Wireless Magazine. He has founded, chaired and organized a number of important conferences and workshops. He has been selected as a member of the Committee on Evolution of Untethered Communication, US National Research Council, and has leaded the US review team for the Finnish R&D Programs. For his contributions in research and scholarship he was the Westin Hadden Professor of Electrical and Computer Engineering at WPI, was elected as a fellow of the IEEE, became the first non-Finn fellow of the Nokia, received the first Fulbright-Nokia fellowship and WPI board of trustee’s award for Outstanding Research and Creative Scholarship. Details of his contributions are available at www.cwins.wpi.edu.

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