Disrupting Engineering Education to Better Address Societal Needs

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ABSTRACT

This paper describes a disruption of "business as usual" in higher education andshares a new and revolutionary education platform designed and developed in Silicon Valley, California in 2014 in an effort develop a new breed of diverse, creative, and interdisciplinary talent into the fields of engineering and technology. The paper describes the motivation and the process used to develop the learning experience designed to address the needs of students, educators, employers, and stakeholders. One that combines learner-centered pedagogy, industry partnerships, and a commitment to continuous development and improvement while at the same time addressing the gender gap.

1 INTRODUCTION - THE NEED

The purpose of higher education is threefold: educate, create and serve society. But for centuries the higher education's structure has changed little. Classrooms look like those of the 19th century, curricula have not evolved much and for the exception of a few new disciplines like computer science or biotechnology, they are mostly disciplinary silos with little interaction with other disciplines. Most faculty are untouchable gods whose primary objective is to create, and in its way bring in external funding. Teaching is secondary (and professors seldom taught how to teach) and service to society other than for personal gain (e.g., consulting), is almost inexistent is minimal due to governance concerns [1]. For engineering education, the current state of higher education way of business has become critical. Back in 1998, William A. Wulf, then president of the US National Academy of Engineering [2] described the urgency for engineering education reform, but since then only minor changes are evident. Now more than ever engineering education needs to be disrupted, innovated and reformed to better serve societal needs. Three issues need to be addressed: the education experience, the skills gap and the student return on investment. Traditional engineering programs focus too much on theory in a single discipline and perpetuate the disconnect between education and industry and society interests. These programs fail to engage 21st century learners, ignoring the plethora of resources and techniques made available by advanced technology. Consequently, many engineering students drop out or change their course of study, others enter the job market without the skills needed to fuel socioeconomic progress [3]. Then, there's the escalating students' loan debt. Since the recession began in 2008, the amount of student loan debt in the US has spiked by 84 percent, with borrowers owing a record $1.2 trillion [4]. Can there be a paradigm shift, a disruption in the higher education "business"?

The urgency to reform engineering education to better address society's needsis global. In short, this was the challengea group of higher education investors (University Ventures)[1]was posed to solve in 2013. Current results of this initiative demonstrate it can be done [5].

1.1 The supply crisis

[1] University Ventures (www.universityventuresfund.com)

Engineering programs are simply not attracting and graduating enough engineers. Therefore there is not enough talent to fill the employment needs. In the United States (US) alone, Science, Technology, Engineering and Mathematics (STEM) jobs are projected to grow by 17 percent over the next decade, making it the most prosperous cluster in the economyand creating 1.2 million new jobs, as well as an additional 1.6 million job vacancies by 2018 due to the retirement of baby boomers. Despite this demand, the number of engineering B.S. degrees granted in the United States has effectively remained flat since 1992 and there has been only a 4% increase in engineering education capacity over the last five years [7]. A large part of the problem is that engineering institutions are not attracting females and minorities. Just 18.1% of bachelor's degrees in engineering in the US were awarded to women in 2010 vs. 57% of total bachelor in Arts degrees [8].

1.2 The competencies crisis

The students who are graduating from engineering programs do not have the competencies needed to address industry challenges of today and tomorrow.A 2015 report on findings from a survey of employers and a survey of college students has found that more and more companies are requiring competencies that go beyond knowledge (the focus of most curricula and teaching) and demand intellectual and practical skills such as oral and written communication, teamwork, critical thinking, innovation and creativity and personal and social responsibility [8].Only 14% of employers think that most of today's university graduates are prepared with the skills and knowledge needed for the workplace [10].In a recent survey on skills gaps in the United States, over 88 percent of American companies surveyed reported engineering positions were somewhat or very difficult to fill, the highest of all occupations [11]. Yet just 42 percent of 2009 engineering bachelor graduates were employed upon graduation [12]. There is also an enormous disconnection between the demand of industry and the supply of correlated engineering disciplines. Over 50% of bachelor's engineering degrees in the US are focused in Mechanical, Civil, and Electrical engineering, all areas of high supply and low demand. Degrees are not being awarded in areas of high demand, such as computer science/engineering and environmental engineering.This suggests engineering students are not graduating with the relevant competencies.A survey of the talent challenge and employability conducted by McKinsey in 2008 had similar results at a global scale [13].

1.3 The retention crisis

Once entering engineering programs, students are dropping out or changing majors at alarming rates. Engineering programs are losing up to 50% of matriculating students due mostly to the challenges of the first two years [13]. More than 22% of STEM majors dropped out of higher education entirely five years after beginning postsecondary programs [14] and 18% of new STEM majors end up earning a bachelor's degree in a non-STEM discipline [15]. This may be due to many factors, including inadequate preparation in base competencies, financial situation, lack of study habits and inadequate teaching methods.

2 THE SOLUTION

Re-engineer engineering education and design a fresh and innovative way or platform to educate engineers toaddress the needs of society and all stakeholders bycombining learner-centered pedagogy, industry partnerships, and a commitment to continuous improvement.The initiative was called New Engineering University (NEU). The following sections detail the institution's academic model from its creation in 2013 until it merged with another entity on June 2014.

2.1 The mission and vision

Developed in partnership with the University of New Haven, in Connecticut, NEU's mission and vision statements read simply to "*educate world class engineers, equipped to attain full employability, through a constructivist learning environment that revolutionizes how students think and feel about engineering education" by making engineering 'REAL' (Realistic, Enjoyable, Accessible, Lean).*

2.2 The core values

The core values the NEU team adopted were founded on the belief that the learning experience should be:

- Transformational and life changing, leading to employment opportunities
- Enjoyable
- Industry-coupled and practical
- Synergistic, meaning than an individual's power can be raised exponentially with the help of a collaborative team
- Affordable and pledged to continuous quality improvement

2.3 The strategies

The following strategies were embraced to help accomplish the mission and vision of educating engineers:

1. Understanding the needs of stakeholders and defining the desired competencies of graduates (knowledge, skills and values) to develop curricula for degrees, certificates and other learning experiences taking into consideration how people learn.
2. Developing engineering and master of engineering degrees in areas at the intersection of industry needs to generate employability and student interest.
3. Developing innovative and fun learning spaces and experiences for students (and faculty) to learn knowledge, practice skills and develop institutional values.
4. Implementing the continuous quality improvement culture, assessing outcomes to grow and expand.
5. Drawing students capable and interested in completing an engineering degree, particularly underrepresented minorities and women who, for a multitude of reasons unrelated to skill and ability, are choosing other paths.
6. Offering a learning experience that is more engaging and responsive to student learning styles (mix of learning resources and modes), employer-relevant and practical (project-based learning) than traditional engineering programs at a lower price point.
7. Hiring professors who are a smart blend of engineers + educators, who explore and implement innovative teaching, and who are mentors.

2.4 The academic model

To train a new class of engineers, educators must emphasize problem solving and design thinking over tools and technology. NEU's curriculum model featured needs/competency-based, learner-centric and project-based instructional strategies, and included opportunities for industry partnerships and continuous development. Specifics of these items are described below.

Needs/competency-based [16]. Following ABET guidelines, NEU's curricula was to be based on the needs of the constituents in the city, region or country where it establishes campuses. Competencies were defined as the sum of the knowledge, skills and attitudes/values students should have by the time they complete the curriculum.

Learner-centric [17, 18]. NEU will focused on facilitating opportunities for students to acquire skills through their preferred learning styles (alone or in teams, passive or active, verbal or visual, systemic or in sequence). Felder's Learning Styles Inventory (LSI) test would be taken by all students and instructors, and learning experiences will then be designed to incorporate the results. Daniel Goleman's Emotional Quotient (EQ) test would also provide students with the assessment of their professional skills and suggestions for improvement. The test would be given at the beginning and end of programs.

Project-based learning [19]. All courses would require projects that address real, societal needs, to be worked out by student teams. The institution would ensure not only that industry projects were available through its corporate partners, but that they motivated and addressed the needs and career goals of a diverse student body (needs/competency-based). Big Data projects, for instance, would address a wide variety of issues at multiple levels, including education (local), health services (national) and climate and transportation (global).

Industry partnerships [20]. Industry partners were essential for developing competency-based curricula. NEU was engaged with industry in various ways: in providing input for establishing competencies for its programs, in developing course material, in teaching and in providing mentorships and practica for students and faculty.

Continuous improvement [21]. Excellence is only achieved through continuous assessment, evaluation and development. NEU was committed to performance, quality, accountability and transparency. It recognized that institutional performance measurement is key to the strategic management of its resources and to rigorous planning for its future. Data and information gathered was therefore key to its mission. A series of key performance measures were carefully chosen to represent high level measures of university activity. They provide baseline data by which the institution could measure the health of its system (and of course, of student's learning). These indicators provide the university governance and members of the wider community with an institutional statistical profile. These measures provided an accountability framework to help make decisions and build on baseline data, keep internal and external stakeholders informed and develop models for strategic planning and decision-making (e.g., curriculum improvement, enrollment planning and analysis).

Finally, the model included the development of "conscientious leadership and active entrepreneurism." All programs would require a Leadership and Entrepreneurism course, focused on developing professional skills and attitudes needed in the practice of engineering (e.g., teamwork, communication, ethics, inclusiveness and diversity, new business development). The development of these professional skills was also integrated into all courses within the curriculum.

4 CURRICULUM DESIGN APPROACH

NEU used a combination of instructional systems and "Backwards Approach (BA)" to design curricula. As a field, instructional design is historically and traditionally rooted in cognitive and behavioral psychology, though recently constructivism (learning theory) has influenced thinking in the field. Instructional Systems Design (ISD) or simply instructional design [22] is the practice of creating "instructional experiences which make the acquisition of knowledge and skill more efficient, effective, and appealing" [23]. Thus, ISD focuses on the learning experience. The process consists broadly of determining the needs of the learner, defining the end goal of instruction, and creating some "intervention" (the "catalytic process") to assist in the transition, and thus, resulting in learning. NEU's instructional design method included these phases (very similar to the engineering problem-solving/design methodology!): analysis, design, development, implementation, and evaluation, described in the section below.

In BA the educator is able to focus on addressing what the students need to learn, what data can be collected to show that the students have learned and how to ensure the students will learn.

4.1 Curriculum design phases:

BA design [24, 25] is a method of designing curriculum by choosing learning outcomes before instructional methods or assessments. This means one chooses the outcome of the learning experience first, and let's that guide the teaching/learning and the assessment/evaluation. This method challenges "traditional" methods of curriculum planning in which a list of content that will be taught is created and/or selected first and teaching/assessment methodology usually are lectures and laboratories, with written exams as assessment of learning. In backward design, the educator starts with goals, creates or plans out assessments and finally makes lesson plans. Supporters of backward design liken the process to using a "road map"

[26]. In this case, the destination is chosen first and then the roadmap is used to plan the trip to the desired destination. In contrast, traditional curriculum planning has no formal destination identified before the journey begins.

Analysis – the first and most important step is to understand the regional and national economic development needs, technology trends and employer needs. The engineering/technology competencies for NEU's first program (Master of Engineering in Big Data) were captured through several ways, including conversations with the institution's Advisory Board, industry representatives, institutional and program accreditation requirements and by benchmarking successful programs worldwide. The competencies for the first program included a combination of big data knowledge, skills, and attitudes/values.

Design –the curriculum design started by distributing the competencies across the curriculum ("roadmap") as shown in Table 1, and establishing the desired depth of learning the competency (scale of 1 to 5). With the assistance of academic and industry experts, more specific learning objectives and desired outcomes were written for each of the individual courses. The courses' syllabi include specific learning objectives and outcomes, weekly course plan, weekly learning experiences, and outcomes assessment for all the competencies assigned to the course, as well as traditional information like title, description, textbooks/references and other logistics. The Felder-Brent definition of learning objectives (or instructional objective *was used: "A statement of something observable and clear that students should be able to do after receiving instruction, plus (optional) conditions under which they would do it and/or what would constitute acceptable performance."* [27]

Learning Outcomes	Outcome 1 - Evaluate and use big data systems engineering to analyze, evaluate, and design technologies in an enterprise setting	Outcome 2 - Design solutions to big data challenges taking economic and societal constraints into account	Outcome 3 - Work in multi-disciplinary, multi-stakeholder, culturally diverse teams	Outcome 4 - Communicate effectively with multiple stakeholders	Outcome 5 - Leverage and influence professional networks	Outcome 6 - Apply security and ethical standards	Outcome 7 - Manage projects and time effectively	Outcome 8 - Respect and embrace diversity and cultures	Outcome 9 - Be flexible and adaptive
*Courses/Depth of Learning**									
CSBD 5001: Introduction to Big Data Technologies	3	-	1	1	1	1	-	1	1
CSBD 5050: Big Data Leadership and Entrepreneurism	3	1	3	3	3	3	3	3	3
CSBD 5002: Big Data Infrastructure I	5	5	1	1	1	3	1	1	1
CSBD 5008: Big Data Infrastructure II	5	5	1	1	1	3	1	1	1
CSBD 5003: Machine Learning and Analysis I	5	5	1	1	1	3	1	1	1
CSBD 5004: Machine Learning and Analysis II	5	5	1	1	1	5	1	1	1
CSBD 5020: Big Data Governance and Stewardship	3 to 5	3 to 5	1	1	1	3	1	1	1
CSBD 5009: Big Data Focus Elective	3 to 5	3 to 5	1	1	1	3	1	1	1
CSBD 5010: Big Data Industry Practicum	5	5	1	1	1	3	1	1	1
CSBD 5051: Big Data Capstone Project	5	5	1	1	1	5	1	1	1

Table 1 Curriculum Learning Outcomes Roadmap

Development – Teams of 2 to 3 subject matter experts with academic and industry experience were tackled with the task of developing each course. This entailed: refining learning objectives, defining topics, resources needed, active learning experiences and assessments. Research shows that students learn better when they know why/what they are learning, when they see applications on how the knowledge is used, when given time to think and share thoughts with others, and when they engage in active learning. Thus, to design the learning experience professors and course designers were to answer the following questions:

- How will students learn?
- What resources are needed?
- When and where will the learning take place?
- Who is responsible?

- What experiences will help students learn the knowledge and develop the skills, attitudes and values?
- How can we address different learning styles?

The teaching/learning strategy dictated by the course objectives, balanced facts with concepts, and included a variety of delivery modes. Therefore, all courses had a blended mix of, for example, short lectures (15-20 min) blended with any activity that would keep students alert, engaged and motivated in the learning process, such as student discussions, in-class demonstrations, laboratory experiences, team projects, and student oral presentations. All courses included learning objectives, desired outcomes and assessment (see section below for more detail on assessment strategy).

Design of the learning space/environment was critical since this was the space where student learning would take place in a constructivist manner, and where students would interact with faculty, industry collaborators, and other students. Called T(H)INKER Space, it was to be a flexible, open space where students, faculty and others can brainstorm ideas, work on projects, develop prototypes, and relax with a cup of coffee—one that will supplement standard classrooms. In other words, the learning environment was to be learner-centric, promoting learning by doing as well as reflection and self-learning. NEU's professors and teaching assistants were to be mentors and focus on catalyzing learning in a fun and motivating environment.

In order to promote the learner-centric and constructivist learning environment, the following steps/actions were to take place:

- All course materials, lecture videos, references, links etc., would be posted on the learning management system (LMS) so those who prefer to learn at their own pace and time can access them at their leisure.
- All courses would be project-based, thus allowing students to practice problem solving and design skills, including problem definition, identification of possible solution/design roadmaps, selection of best alternative based on real-life constraints to solving/designing in communication with the customer (need) — all of which are constructivist in nature.
- Constructivism promotes hands-on learning, thus, in addition to having traditional classrooms for lectures, the institution's T(H)INKER Space would have multiple places (including labs and computer workstations) where students would experiment and work on their class and capstone projects, meet in teams to discuss their work, reflect on issues, meet with industry representatives, meet with faculty informally, etc.
- All students were to work in teams in real-life projects/problems from the first day of class.
- A project fair to be held at the end of the academic year, where teams would present their project work to industry and community sponsors. High school students were to be invited to attend the fair so that they could learn more about engineering and the institution's academic programs.

These carefully selected elements, delivered in a dramatically expansive physical environment, combined to create a new breed of engineer—smart, diverse, creative, and passionate about making a difference in the world.

Implementation – NEU's first degree, a one year, 30 credit hours Master of Engineering in Big Data, was developed using this approach and with the following characteristics:

- Cohort mode (a group of students working in teams from day 1 who would the same set schedule and progressed together).
- Lecture sessions (captured to be available on-line 24-7) would include frequent hands on activities, group work, demos, etc. and include guest speakers from industry.
- Program would require an internship and a capstone project in industry. This academic model's implementation calls for a new breed of professor.

- Scholarships for women and minorities
- 50% of faculty from industry, non-tenured, with new roles and responsibilities (including industry sabbaticals every three years, securing projects from industry) and novel rewards and recognition (bonus for good teaching, cultural trips)

Evaluation –Two assessment cycles were designed: (1) external survey and focus group feedback reviewed by the external Advisory Council, to be carried out every three years, to evaluate program objectives and outcomes; and (2) internal course assessments (direct and indirect methods) to evaluate student learning outcomes and provide faculty and administration with information to make adjustments to continuously improve the program.

5 CURRENT STATUS

In June 2014 NEU was acquired by a group and rename it GalvanizeU[2]. It will be launching the first program in 2015.

5SUMMARY AND ACKNOWLEGDMENTS

What makes this platform unique in educating locally relevant globally competent engineers? It is a constructivist learning environment that revolutionizes how students think and feel about engineering education that responds to a region's needs for competencies and develops a new breed of thinkers and innovators through a new breed of educators and mentors. It is a smart blend of learning in a fun environment that promotes learning. The author wishes to thank University Ventures for the opportunity of being given a blank slate to develop this model which can serve the engineering education community in developing/innovating their learning experiences to better serve society.

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