Lessons from Leaders on Modernizing Higher Education Engineering Curriculum

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SUMMARY: In colleges and universities across the country, engineering programs are experiencing an epic revitalization—blurring the lines between class and career, and increasing access to dynamic, hands-on learning and projects—to keep pace with the rapid change of industry. This paper offers a brief glimpse into the best practices for driving change within engineering programs, and the benefits that have been realized.

Section 1. Meeting the Gap of One Million

The United States currently awards about 300,000 bachelor and associate degrees in STEM fields annually. While that may seem like an impressive number, it’s only a fraction of what’s needed to meet pending global challenges. Economic projections¹ indicate approximately a million more college graduates in STEM fields are needed over the next decade, for the U.S. to retain its historical preeminence in science and technology, and to address the engineering issues confronting the world today and tomorrow.

¹ PCAST Engage to Excel Report
To meet this goal, the U.S. will need to increase the number of students who receive undergraduate STEM degrees by about 34 percent annually. Merely increasing the number of STEM majors who stay with their programs through graduation from the current rate of 40 percent to 50 percent would generate three-quarters of the one million additional STEM degrees needed over the next decade. What must happen to achieve such a significant increase of students who choose a STEM degree, or at least stick with it once they’ve started?

In early 2017, at the annual ABET Symposium, academic leadership from STEM programs across the country shared their viewpoints, noting in most cases that the issue goes far beyond enrolling and retaining more students in STEM degree programs. Rather, the broader issue they see for these institutions is the need for them to innovate how STEM education is offered to engage student populations effectively, and help them develop the skillsets that are — and will be — most needed by a rapidly evolving global economy.

This paper highlights several university programs across the country that have been successful at driving curriculum change to better meet the needs of their student populations and the surrounding business communities. Each featured university has unique elements, which are threaded together here as considerations and key learnings for the higher education community.

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Section 2. A Baseline for What Works

Institutions of higher learning, and particularly those with programs in the STEM fields, have been implementing proactive and innovative steps in recent years to design and deliver curriculum that is outcomes-based, informed by real-world business needs that give students core discipline knowledge while retaining a student’s ability to explore individual interests. Universities that have made such adjustments report direct improvements in their ability to increase general enrollment, improve retention in STEM degree programs and develop more thoughtful and prepared graduates who then contribute to the nation’s standing as a STEM leader.

While driving curriculum change can often be slow, these institutions are leading the way in keeping curriculum relevant to the real-world needs of today’s employers in a time of rapid change.
Section 3. The Olin College Story

Understanding the Olin College of Engineering’s approach to delivering its engineering curriculum requires first understanding the undergraduate experience of the college’s president, Richard Miller. The first seven semesters of Miller’s undergraduate studies were filled with courses focused on engineering theory. It wasn’t until his eighth and final semester that he’d put what he learned into practice. While Miller went on to receive a fellowship to Massachusetts Institute of Technology (MIT), he knew that his undergraduate experience had not effectively prepared him for the practical side of a career in engineering.

Decades later, when he received an invitation from Olin College to design a new engineering program from the bottom-up, he knew that in addition to delivering the basic science of engineering, the curriculum needed to engage students in the act of discovery and hands-on learning, right from day one.

“Engineering is to physics what medicine is to biology,” says Miller. “One can’t become a surgeon from simply reading textbooks. At some point they’ve got to pick up a scalpel.”

Under Miller’s leadership as Olin College’s president, the Needham, Mass.-based school has become a model for how to develop accomplished graduates who have the knowledge and the skills to engineer solutions for real-world problems.

Olin’s program boasts a 50 percent female enrollment and regularly produces engineers who, upon graduation, run enterprises that were conceptualized in their dorm room, designed in the classroom and nurtured through collaborative problem solving with peers and mentors.

Every graduate leaves Olin with a minimum of 25 case studies that describe the projects, systems, hardware and other technologies they’ve built during their studies, along with their resume and transcript. According to Miller, employers who hire Olin graduates routinely report that Olin students enter the workforce as though they’ve been working professionally for at least two years.

To date, more than 2,000 faculty from 750 institutions of higher education, representing 50 countries, have visited Olin to learn from and model its unique project-based curriculum.

What they learn is that Olin’s road to success wasn’t paved by traditional means. Instead of starting with Miller’s vision and hiring faculty who were known for their strong ideas and innovative thrust, Olin looked toward the young people they wanted to cultivate.

“Many of the individuals who were engaged in the two-year curriculum development process had no experience at all,” says Miller. “The new ideas created by this committee of young people were much more creative than I could have imagined, and it has paid off in new students being able to relate with and remain engaged in the program experience.”
Experimentation was key to Olin’s curriculum development process. “An engineer is a person who envisions what has never been and does whatever it takes to make it possible,” Miller argues. “With this definition, we developed and tested our theories until we found the best solutions to improve and increase the flexibility of a dated approach to engineering learning.”

Section 4: Finding Commonalities in Curriculum Change

Olin College is far from alone in its intentional focus on collaboration and experimentation. Experts in universities, business and higher education accreditation agree that certain elements must be at play in order for such change to take hold, and collaboration is at the top of that list.

CAPITOL TECHNOLOGY UNIVERSITY — HANDS-ON COLLABORATION

Take, for instance, Capitol Technology University in Laurel, Md. According to Nayef Abu-Ageel, dean of academics and chair of the electrical engineering department and one of the visionaries behind the school’s innovative approach, “Capitol is a very collaborative environment. People work in teams across different disciplines, from computer science to cybersecurity, engineering and business. And core to that collaboration is the dynamic hands-on element of the program.”

At Capitol, there is a lab component to every single engineering course. “We have found that when students study content, they may understand it, but they tend to forget the lesson quickly. However, when they learn using their own hands, the information can be retained for a much longer period of time.”

At Olin, that same approach is used, which is why it’s called the Olin model. The hands-on education, combined with collaborative experiences across the humanities, Abu-Ageel believes, is what will become increasingly important for electrical engineers in the future, especially as innovators seek out new solutions to problems facing society.

But how do we get there? Abu-Ageel suggests that developing such a collaborative and cross-disciplinary culture requires universities to keep a close eye on what local industry needs, and then pivot when necessary.

Capitol, which is located in close proximity to NASA’s Goddard Space Flight Center, has become an educational conduit for astronauts careers, and it regularly partners with NASA on curriculum development. “If there’s something we don’t have yet, we can implement it, or if what we have needs tailoring, based on new technologies or new needs, we can do that too,” added Abu-Ageel. At the same time, it’s important to look across the traditional barriers of curriculum, for instance, by developing programs that bridge electrical engineering and business.

To help prepare its students for careers at NASA and the NSA, Capitol has fostered creative partnerships with area high schools, where Capitol students apply what they’re learning in the classroom. “We’ve created custom after school programs where Capitol students act as mentors to rising juniors and seniors in high school. The win-win partnership brings added value to the community, broadens the experiences of high school students and creates a pipeline of future Capitol students. It also gives current Capitol students a chance to teach back what they’ve learned in the classroom, further cementing the practicality of their education.”

For Capitol, just as with Olin, the success of the program didn’t happen overnight and required experimentation in programming. Many Capitol students arrive on campus weak in their math and reading comprehension skills. University leadership realized that in order for their student population to succeed, the first-year experience needed some rethinking. Rather than offer a standard circuits course in the first year, which was challenging for most students to pass, Capitol split the program into two courses, allowing students more time to comprehend the lessons. Almost immediately, there was an increase in the student success rate, and that success then followed many of those students through the remainder of the program. “You must know which elements of the curriculum are hurdles for the students,” notes Abu-Ageel. “But you won’t ever know where those hurdles lie if you don’t regularly interact with your stakeholders. Our success lies in our ability to fundamentally understand our student population.”

Worcester Polytechnic Institute — Project-based Learning

At Worcester Polytechnic Institute (WPI) in Massachusetts, learning has always been about combining theory and practice. “Students are immediately immersed in an experiential learning environment where entrepreneurial thinking and risk-taking are encouraged,” says Michael Gennert, professor of computer science and founding director of the robotics engineering program at WPI. “Our motto is Lehr und Kunst, meaning ‘theory and practice’ and it’s reflected in our approach.”

Realizing that no single discipline sufficiently provides the scope and range of knowledge demanded of engineers, WPI employs an interdisciplinary approach. For example, robotics engineering students will take classes in computer science, mechanical engineering and electrical and computer engineering departments. The engineering components teach students how to build the body of a robot, while computer science focuses on how to control its behavior. Studies aren’t limited to just the technological aspects of the field. Students are also well-versed in the social and ethical implications of robotics.
postdoctoral students, and leverage industry resources to help them develop the knowledge and practical skills that they then showcase in competitions.

In 2016, WPI’s project-based curriculum received the prestigious Bernard M. Gordon Prize for Innovation in Engineering and Technology Education. The Institute is hosted and run by WPI in partnership with the Association of American Colleges & Universities. The Institute seeks to align WPI’s robotics engineering program in the United States. The while the basic structure of WPI’s project-based curriculum has remained the same since its inception in the 1970s, the faculty and staff have embraced many changes over the years. “Our foundation has proven to be really sound because of the decades of experience and solid pedagogy that faculty and staff brought when developing the curriculum,” says Gennert. “This allowed us to focus on growing the program and making sure that the tools students have access to, from laboratory equipment to harbor platforms and languages, evolve with time to remain relevant to industry.”

For example, WPI’s robotics engineering offerings have grown from five in 1992 to more than 20 robotics-specific courses. The robotics program has experienced exponential growth in the number of students and faculty members, and they’ve become a sought-after institution for influential robotics organizations seeking opportunities for collaboration.

The higher education community has also benefited from WPI’s leadership through its Institute for Project Based Learning. Faculty from colleges and universities all over the country come to WPI to learn how to teach immersion and hands-on, project-based training with expertise in innovation. The Institute is hosted and run by WPI in partnership with the Association of American Colleges & Universities, the leading national association focused on undergraduate liberal education. Gennert credits three intersecting areas of merit: academic, strong pedagogy and experienced faculty and staff at the helm; financial, the ability to show a future return on an investment in staff and equipment; and political, the ability to get support from university leadership to get the job done. With focused support from academic leadership that wanted to see something new, bottom-up faculty support, and a solid financial plan, program directors are empowered and equipped to design a rigorous course curriculum that could meet a growing need for engineers in the greater Boston area.

PROFESSOR OF MECHANICAL ENGINEERING, ROSE-HULMAN INSTITUTE OF TECHNOLOGY

Patricia Brackin

“Rice University (and other universities) saw that building this kind of innovation-focused education that aligns — rather than competes — with the core curriculum would make them relevant in the 21st century.”

Rice University and the Rice Alumni Network have been at the forefront for undergraduates, maximizing connections with the Rice alumni network and the startup community in Houston. Yael Hochberg, Head of Rice University Entrepreneurship Initiative

“In response to undergraduate student requests for an innovation-focused education that aligns — rather than competes — with their course of study, Rice University introduced a new Entrepreneurship & Innovation minor in the fall of 2016. Jointly offered by the School of Engineering and the Sloan School of Management, and engaging departments and centers from across campus, the ESI minor educates students how to serve as leaders in the innovation economy, with the knowledge, skills and confidence to develop, scale and deliver breakthrough solutions to real-world problems.”

A similar focus on entrepreneurship is underway in Houston, where Rice University’s Entrepreneurship Initiative is bridging the academic experience across the liberal arts, professional schools and the research university. The new Liu Idea Lab for Innovation and Entrepreneurship (LILE), announced in 2016, and opening in the fall of 2017, will feature new and expanded entrepreneurship courses as well as projects to encourage ideas and achieve success in entrepreneurial endeavors.

“Rice students come from a wide range of backgrounds; the Liu Lab will be a community for them that aims to create a dynamic undergraduate experience that is increasingly critical to lead in entrepreneurship in higher education. Lile puts this experience at the forefront for undergraduates, maximizing connections with the Rice alumni network and the startup community in Houston.”

“The MIT Innovation Initiative (MITii) is bridging the academic experience with real-world problems. MITii serves as a connector across the many innovation and entrepreneurship programs on campus; it supports the expansion of existing programs to serve more students; and it is creating new education, research and infrastructure efforts to fill key gaps in the landscape of opportunities. With this remarkable commitment to entrepreneurship, Rice has created a platform for building expertise in the innovation process with insights developed from the evidence-based science of innovation. MITii continues to serve as one of the most powerful engines of innovation in the world.”

A dynamic undergraduate experience is increasingly critical to lead in entrepreneurship in higher education. Lile puts this experience at the forefront for undergraduates, maximizing connections with the Rice alumni network and the startup community in Houston.”

Patricia Brackin

Professor of Mechanical Engineering, Rose-Hulman Institute of Technology

Rice University’s E-teams Entrepreneurship Exper- ence course, offered through Lile, will be open to all undergraduate students. Interested students will focus on a single project sourced from a Houston startup company. They will meet with instructors and entre-
In researching each of the stories outlined above, six distinct themes — lessons learned — emerged as central to the design of effective and flexible engineering program design.

1. **The blurring of disciplinary borders**: Higher education is no longer a straight line within any given program area. Rather, the most compelling programs are those that blend learning across many diverse program areas.

2. **Holistic approach to problem solving**: Learning to solve a problem is about much more than memorizing the math equation. By deeply engaging real-world practice into the classroom, students learn beyond the theory in a way that can make them better problem solvers for life.

3. **Informed by business**: From cross-sector learning to corporate pipeline programs embedded inside the classroom, innovation in education is increasingly important in building tangible success for graduates, as well as the universities in which those students thrive.

4. **Customizable curriculum**: Flexing with the needs of the business community has become critical for universities to show value to students and corporate partners, as is the process for allowing students an opportunity to chart their own course, with flexibility and choice in program elements.

5. **Dynamic, hands-on learning**: The environment in which one learns, tests, and problem-solves is just as important as the frame in which one is learning. Exposing students earlier to real-world challenges is increasingly important as society confronts the demanding population and infrastructure challenges of the next several decades. This emphasis and approach to problem solving came across clearly in all programs we examined. Teamwork and project-based are the new principles of education.

6. **Effective Assessment**: Curriculum is no longer static. Through regular and effective assessment, as provided by ABET and other program accreditors, universities have the tools and confidence needed to be the best they can be for their students, donors, and corporate partners.

**Section 6 Conclusion**

Integrating hands-on learning, an entrepreneurial mindset and a global perspective into any engineering curriculum can be a lengthy and complex process especially in the context of well-established curriculum components and university structures, but as the case studies here point out, the impact of embedding such principles in to coursework can be extraordinary for the students’ learning experience.

To remain relevant in the competitive higher education landscape and to effectively develop students who can meet the needs of today’s global economy, university leadership must be thoughtful about how to get our students from here to there. A spirit of exploration, flexibility, innovation and experimentation must become a natural part of the learning process, and the delivery of education in general must be nimble enough to evolve as technology evolves.

**Section 7 Acknowledgements**

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**Section 8 About ABET**

ABET is a forward-thinking, purpose-driven organi-zation recognized by the Council for Higher Educa-tion Accreditation (CHEA). A federation comprising 35 professional and technical member societies, we accredit college and university programs in the areas of applied and natural science, computing, engi-neering and technology education at the associate, bachelor and master degree levels.

Based in Baltimore, our reach is global and we have 3,852 programs in 776 institutions in 31 countries. We provide accreditation for post-secondary programs within degree-granting institutions already recognized by national or regional institutional accreditation agencies or national education authorities worldwide. Our accreditation is voluntary. With ABET accreditation, students, employers and society can be confident that a program meets the quality standards that produce graduates prepared to enter a global workforce.