Engineering Change

Students study at Olin College.

Lessons from Leaders on Modernizing Higher Education Engineering Curriculum

An ABET Issue Brief
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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**

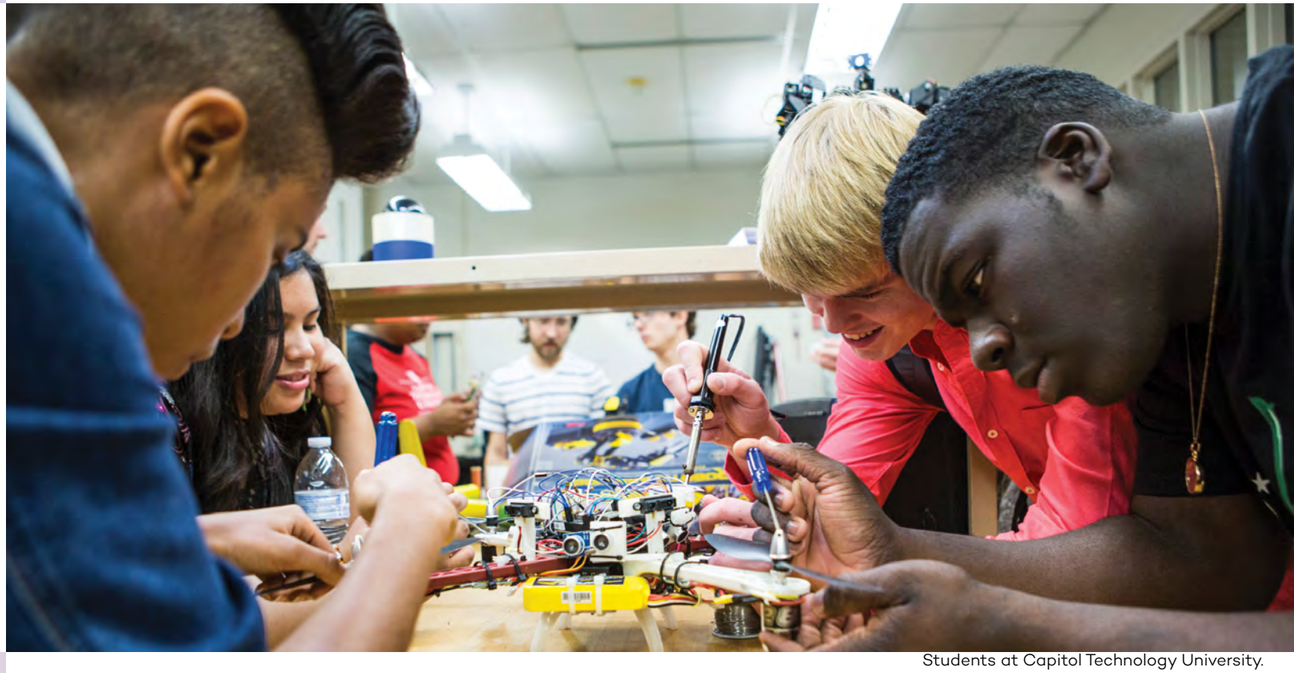
The United States currently awards about 300,000 bachelor and associate degrees in STEM fields annually. While that may seem like an impressive number, it's only a fraction of what's needed to meet pending global challenges. Economic projections[1] indicate approximately a million more college graduates 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

“We have an obligation to communities to help improve the human condition. This generation of engineering students are socially connected and helping them understand how engineering can help solve societal problems will bring more of them into the field of engineering. It’s our responsibility to improve the human condition by the work that we do and the people that we train.”

Darryl Pines
Dean and Nariman Farvardin Professor of Aerospace Engineering
A. James Clark School of Engineering, University of Maryland, College Park

Darryl Pines speaks at the 2017 ABET Symposium.



Students at Capitol Technology University.

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.

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.

Students study at Olin College.

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 text books. 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."

Dr. Nayef Abu-Ageel, Capitol Technology University

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.”

That commitment to 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 our 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 astronautics 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.

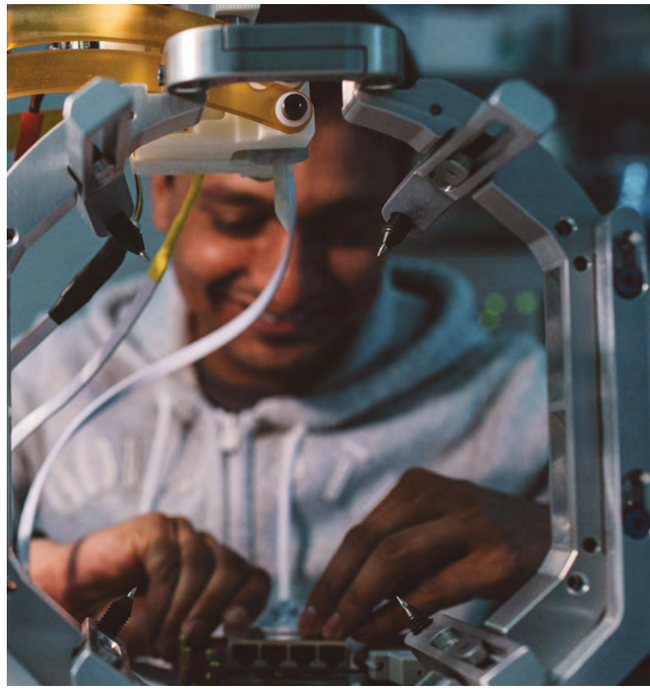
To help prepare its students for careers at NASA and the NSA, Capitol has fostered creative partnerships with area high schools, where Capitol students apply what they’re learning in the classroom. “We’ve created custom after-school programs where Capitol students act as mentors to rising juniors and 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.



Student at Worcester Polytechnic Institute.

The robotics program is just one example of how WPI employs their project-based approach. Since 1970, project-based learning has been at the core of WPI’s curriculum and features integrative project work across four years, both in the major and in general education, in classrooms and around the globe at our more than 40 project centers. Students work closely with faculty and each other to develop solutions to real-world problems in their own communities and in communities around the globe. Participating in team and individual research settings, students tackle authentic, open-ended projects under faculty guidance. During the process, they master critical thinking, sharpen research skills, fine-tune written and oral communication skills and connect the curriculum to local and global issues.

Outside of the classroom, students are exposed to high-level, hands-on learning and capstone projects that are supported by industry. Students also benefit from the ability to collaborate with graduate and

"Our classes prepare engineering students for multiple careers in a rapidly changing environment. We emphasize fundamental concepts and techniques that will last longer than present technology."

Patricia Brackin

Professor of Mechanical Engineering, Rose-Hulman Institute of Technology

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. In the same year, ABET also honored WPI's robotics engineering program with its inaugural Innovation Award after it implemented the first ABET-accredited undergraduate robotics engineering program in the United States.

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 has 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 expanded over the last 10 years to include new master's and doctorate programs and more than 20 robotics-specific courses. The robotics program has experienced rapid growth in the number of students and quality 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 immersive and hands-on, project-based learning. The annual program is a 2.5-day intensive workshop where teams of five or more faculty and administrators can gain knowledge about project-based learning and make tangible progress to integrate those concepts into their own curricula. 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.

How did WPI lay the foundation for such success? 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 top-down 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.

ROSE-HULMAN INSTITUTE OF TECHNOLOGY — IMPLEMENTING REAL-WORLD SCENARIOS

Presenting the impact of engineering in real-world settings is a core principle for Rose-Hulman Institute of Technology, in Terre Haute, Ind. At Rose-Hulman, nearly every student in the engineering program experiences program theory through focused small-team work, from the student's very first freshman year course. Team projects where students develop solutions to authentic real-world problems using the theory they've learned in the classroom are consistently included throughout the curriculum starting in the freshmen year. Rose-Hulman students also receive access to corporate partners to advance their careers while directly supporting the growth of the regional economy.

Since its inception, Rose-Hulman's mission has been to offer the world's best undergraduate STEM education. To do this, the staff, faculty and leadership at Rose-Hulman have paid close attention to its students, their strengths and technology itself.

"For almost 150 years, our mission has been to offer the world's best undergraduate STEM education in an environment of individual attention and support," says Patricia Brackin, professor of mechanical engineering at Rose-Hulman. "In the last 10 years, there have been many advances in educational technology and in research on how people learn best. This has allowed us to take those defining elements of a Rose-Hulman education to a new level, offering an individually-engineered STEM education to the next generation of leaders in science and engineering. Our model is designed to prepare students for challenges they will face long after they graduate."

Rose-Hulman's commitment to maintaining a current learning environment has positively impacted students and the college as a whole. "Students are empowered to take ownership of their learning, which increases their level of engagement and prepares them for careers in an industry where innovation and creativity are necessary for success. Not only are students well-equipped to make an impact in their chosen STEM fields after they have graduated, they are also inclined to make an impact globally and return to Rose-Hulman as alumni to speak, advise and mentor," Brackin explains.

Nan Mattai, of Rockwell Collins, has said that the company's partnership with Rose-Hulman has "allowed us to engage with targeted departments on curriculum changes to better meet our future business needs, to gain early access to students for our internship and co-op programs, and to enhance our ability to recruit exceptional graduates who are a great fit for our company."

The key to Rose-Hulman's successful STEM programs is the college's ability to pinpoint, highlight and build upon their strengths. "One of our greatest strengths is our ability to develop leaders in an environment where students receive individual support and attention from the moment they first step onto campus through — and even beyond — graduation," says Brackin.

MIT AND RICE UNIVERSITY — STORIES IN INNOVATION AND ENTREPRENEURSHIP

In September 2012, incoming MIT President L. Rafael Reif noted the Institute was already a global leader in innovation but recognized the need to push the science of innovation forward. "With the right facilities, alliances, and programs," he stated, "we can build on that lead and continue to serve as one of the most powerful engines of innovation in the world."

The MIT Innovation Initiative (MITii) works with all five MIT schools to strengthen the educational pathways and networks for students, alumni and partners to move ideas from conception to impact. It does so by combining hands-on, global opportunities for building expertise in the innovation process with insights developed from the evidence-based science of innovation. 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.

MIT is refashioning its entrepreneurship curriculum with courses that integrate existing discipline-based training with expertise in innovation. The curriculum is designed for undergraduate, graduate and postdoctoral education, and it is focused on moving from idea and invention to action and the marketplace. MIT faculty and experienced entrepreneurs will bring clinical prowess and real-world experience into the classroom. Many of the new courses will involve team learning where students from various disciplines form groups that focus on innovation challenges.

In response to undergraduate student requests for an innovation-focused education that aligns — rather than competes — with their course of study, MIT 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 E&I 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 (Lilie), announced in 2016, and opening in the fall of 2017, will feature new and expanded entrepreneurship courses as well as projects to encourage Rice students to pursue and achieve success in entrepreneurial endeavors.

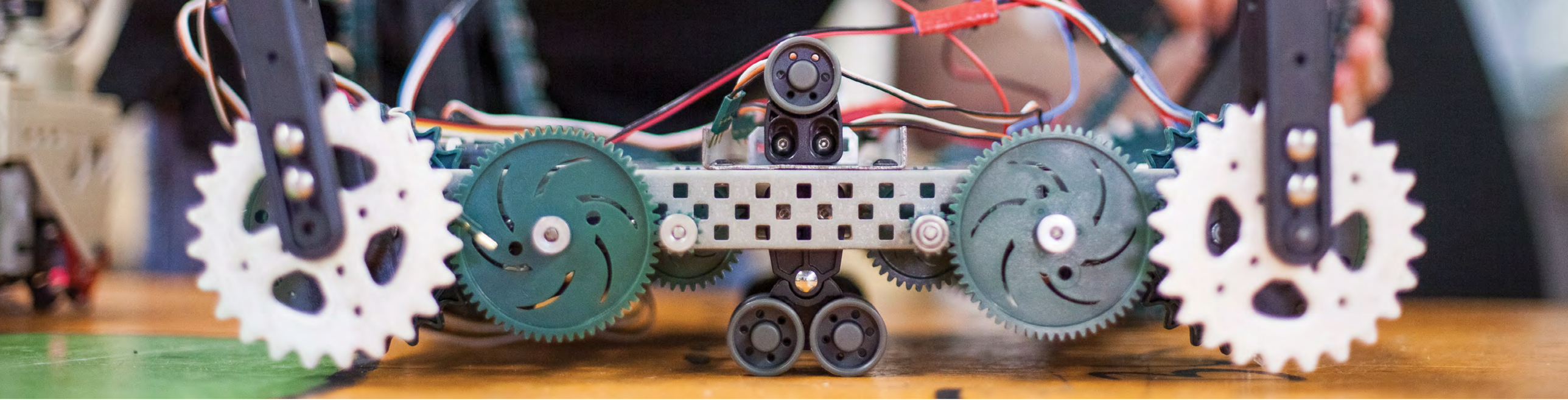
"A dynamic undergraduate experience is increasingly critical to lead in entrepreneurship in higher education. Lilie puts this experience at the forefront for undergraduates, maximizing connections with the Rice alumni network and the startup community in Houston."

Yael Hochberg

Head of Rice Entrepreneurship Initiative

"With this remarkable commitment to entrepreneurial experience and opportunity, Rice University is making a strong statement about being a top choice for students who want to learn how to bring innovative ideas to life," said university president David Leebron. "By providing hands-on opportunities to learn entrepreneurship through Lilie's innovative courses and programs, we hope to attract talented and driven students and equip them with the necessary resources to lead innovation both on Rice's campus and across the city of Houston and the state of Texas," said Frank Liu, the 1978 civil engineering graduate who invested $16.5 million to bring Lilie to life.

Rice University's E-teams Entrepreneurship Experience course, offered through Lilie, will be open to all undergraduates. Interdisciplinary teams will focus on a single project sourced from a Houston startup company. They will meet with instructors and entre-



Robotics project at Worcester Polytechnic Institute.

preneurship mentors, set progress goals and present their projects to a panel of reviewers that include the startup from which the project originated. The course will train students to solve problems, improve teamwork and strengthen communication. "E-Teams will offer students a unique opportunity to learn about the challenges and opportunities of entrepreneurship while immersing themselves in the local startup community," said Yael Hochberg, Ralph S. O'Connor Professor in Entrepreneurship (Finance) and head of the Rice University Entrepreneurship Initiative. "We expect this exciting program will inspire a wide range of Rice students to think entrepreneurially."

Such opportunities for experiential education, leadership development and hands-on research are an integral component of the Initiative for Students, Rice's three-year volunteer engagement and fundraising effort. Rice students have indicated that they highly value this type of learning, and the university has made such experiences for students a priority.

Section 5. **Lessons Learned**

For students to be competitive in the 21st century, they cannot be taught in 20th century ways. Rather than "teach-memorize-test-repeat," the new model is about dynamic, hands-on learning and projects. That can mean, for example, a single project that a group of students work on throughout their program years, learning whatever they need for that project. Often, faculty serve as a guide, assisting students with the learning process, so that when students graduate, they will be confident in their abilities, well integrated into the industry and have the skills to excel.

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. Universities must go beyond theory to bring practical experiences from outside of the classroom into the learning environment.
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 organization recognized by the Council for Higher Education 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, engineering and engineering technology 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.

415 North Charles St
Baltimore, MD 21201
www.abet.org