Board 48: Partnering with Industry to Establish a New University Engineering Program

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Abstract

A small private university is partnering with industry to establish a new engineering program designed to help meet industry's growing demands for engineering graduates. While there are existing engineering programs at some large public and private schools in the state, they are not producing enough graduates to meet the demands in the region. Industry provided input to help determine what initial degrees would be offered: Mechanical Engineering and Electrical Engineering. They also provided specific input on some of the unique courses in the program. Many of the local employers are in the aerospace industry so the new program will be taught from an aerospace context. This paper will discuss the unique partnership between industry and academia to help establish a brand-new industry-focused engineering program.

Introduction

Many have called for reforms in engineering education. Rugarcia et al. (2000) argue that engineering education instructional methods have changed very little in decades despite research that recommends more effective methods [1]. Tryggvason and Apelian (2006) write, "we need to examine the (engineering) curriculum from a new perspective and accept the possibility that changes that go beyond minor tweaking are needed" [2]. Duderstadt (2008) writes, "Study after study has suggested that profound transformation is necessary in engineering education to prepare engineers for a rapidly changing world" [3]. Mohd-Yusof et al. (2015) write, "Given the current and future challenges in engineering practice, as well as the requirements on engineering graduates, engineering education clearly need (sic) to be transformed from the current practice" [4].

Despite numerous calls for reform of undergraduate engineering education over a long period of time, relatively little has changed. An exception is Olin University, which was founded as a brand-new university based on a very large endowment [5]. However, that model is not easily replicable. Long-standing engineering programs have changed very little in the past couple of decades. Lang et al. (1999) write, "In an era of unprecedented technological advancement, engineering practice continues to evolve but engineering education has not changed appreciably since the 1950s" [6]. While there are some bright spots, real changes have been far too small and slow. This is ironic because technology, typically developed by engineers, changes very rapidly. It is also ironic because many engineering professors work on cutting-edge research, while teaching their courses essentially the same way for many years. Engineering education has not kept pace with a changing world. While there are many possible reasons for the lack of progress, one solution is to launch a brand-new program with intentional design to implement suggested research-based and industry-recommended improvements. This paper describes such a new program.

Engineering Education Deficiencies

Many deficiencies have been identified for U.S. undergraduate engineering education. Some of them are discussed below. They have been identified by both institutions and industry. While there have been numerous technological advances and changes in engineering practice in the past few decades, engineering education has been slow to change [7]. William Wulf, former President of the National Academy of Engineering, believes that engineering education is out of touch with the practice of engineering [8]. He argues that engineering education reform is urgently needed. This includes updating the curriculum, encouraging industrial experience for faculty, and promoting diversity.

Arlett et al. (2010) discuss the drivers for changes in engineering education to meet the needs of industry [9]. These include the development of "experience-led degrees," which mean they include components of "an engineering degree that develop industry related skills and which may include industry interaction." They studied six U.K. institutions and concluded that industry and academia must work together to develop experience-led engineering degrees.

Much has been written and discussed about what industry needs from new engineering graduates that are not currently being provided in too many cases (e.g., [10]). A National Academy of Engineering report (2005) calls for more interaction between industry and academia because most engineering students go to work in industry [11]. The report calls for the reinvention of engineering education. Russell Rhinehart (2014) writes, "After 13 years in industry and 28 in academia, I have concluded that neither the academic perception of excellence nor the tasks students are required to complete align with the perceptions and tasks that lead to success in industry" [12]. While many shortcomings have been cited, this paper will focus on the following deficiencies: too theoretical, weak on soft skills, and not enough focus on innovation. They are considered next including how they will be addressed in the new engineering program.

Too Theoretical

Some refer to academia as the *ivory tower* because of the frequent disconnect with reality. In engineering, reality or the "real world" refers to industry where engineers design real products and services to meet client demands. Curry (1991) writes, "Engineering education is under attack from industry, engineering societies, the federal government, and even the schools themselves. The consensus of opinion: colleges and universities are producing great scientists but mediocre engineers" [13]. Many of the proposed reforms of engineering education have recommended including a stronger connection between industry and academia. However, this has not always been the case. Froyd et al. (2012) noted that the shift from more practice-oriented to more science-oriented instruction occurred during World War II, in part due to the breakthrough contributions physicists made to engineering [14]. Seely (1999) notes the gulf that developed between engineering schools and industrial practice [15]. Shepperd et al. (2009) learned from an extensive study of engineering education the "imperative of teaching for professional practice" because of the generally weak link between industry and academia [16]. Akili (2019) notes that too often brand-new engineering faculty ironically go straight from graduate school, with no industrial experience (practice), to teach practice-related courses [17].

Engineering students clearly must learn the fundamentals of engineering to become successful practicing engineers. However, they must also see the connection between theory and actual practice. A key finding of a Royal Academy of Engineering study (2006) is that engineering courses need to show how theory is applied to real problems [18]. Students want to know how the theory is used in actual practice. Most engineering faculty are challenged to show that connection because they have not practiced in industry themselves. Failure to provide a suitable link between theory and practice is de-motivating for students as they want to know what they will be doing when they graduate and enter the workforce as engineers.

A Royal Academy of Engineering report (2007) notes, "universities and industry need to find more effective ways of ensuring that course content reflects the real requirements of industry and enabling students to gain practical experience of industry as part of their education" [19]. Kirschenman (2008) argues part of the problem is the lack of industry experience for engineering faculty [20]. He writes, "This experiment (after the Russians launched Sputnik 1 in 1957) of not having practical experience to teach engineering – a profession of practice – has not served the engineering profession very well and it is time we move on from that concept." However, there are some major challenges, such as getting engineering faculty some industrial experience and changing the promotion and tenure system accordingly. Kirschenman makes the bold statement, "Engineering is alone among professional careers that try to educate future professionals with people that are not proficient in the practical side of the profession" [20]. This compares, for example, to medical faculty who are also often practicing physicians.

An important goal of an undergraduate engineering program should be to prepare students for professional practice since the majority of graduates will go into industry. In a landmark study funded by the Carnegie Foundation for the Advancement of Teaching, Sheppard et al. (2009) recommended better alignment between the preparation of engineering students and professional practice [16]. They write (pp. 169-70), "the central lesson that emerged from our study is the imperative of teaching for professional practice, with *practice* understood as the complex, creative, responsible, contextually grounded activities that define the work of engineers at its best."

The new engineering program discussed here will attempt to have a better balance between theory and application. Wherever possible, discussions on theory will be followed by examples of real-world applications using the theory. Employers want engineers who are more than "book smart;" they want engineers who can apply theory to actual problems, particularly ill-structured problems where all of the data and boundary conditions may not be well prescribed.

<u>Weak on Soft Skills</u>

Engineering students must learn a broad range of skills to become successful practicing engineers. Besides the ability to solve a wide range of problems, which are sometimes referred to as "hard skills," engineers also need so-called "soft skills" to be effective professionals [21]. Some of these soft skills include the ability to work in multidisciplinary teams, effective oral and written communications, and innovative thinking. Buonopane (1997) notes that engineers spend more time communicating than on generating answers to engineering problems [22]. This is increasingly the case as more calculations previously done by hand are computerized. Sageev and Romanowski (2001) surveyed engineering graduates and found a direct correlation between the amount of technical communication instruction they received as students and their future career advancement [23]. However, they argue there is overwhelming evidence that graduating engineers are not adequately equipped to meet the need to convey technical information to diverse audiences. A National Academy of Engineering study (2004) notes that good engineering requires good communication skills [24]. Martin et al. (2005) found that many studies have identified that communication and teamwork have been consistently identified as competency gaps [25]. Galloway (2008) argues that, while engineers have strong technical skills, their communication skills are generally weak [26]. In a meta study, Passow and Passow (2017) found that engineers spend 55-60% of their time communicating [27]. In order for an engineering program to receive ABET accreditation, they must show that their graduates satisfy Student Outcome 3, which is "an ability to communicate effectively with a range of audiences" [28]. Most universities require engineering students to take general English courses which do not generally provide adequate instruction on technical communications.

The new engineering program described here will include a course specifically on technical communications (described below). This knowledge will be used in both oral and written communications throughout the program, culminating in the capstone project.

<u>Lack of Innovation</u>

The pace of technological innovation is increasing. A recent example is the advancement in artificial intelligence, which has the potential to dramatically change many aspects of our lives. The ability to innovate is becoming increasingly important to business success [18]. Duderstadt (2010) writes, "As technological innovation plays an ever more critical role in sustaining the nation's economic prosperity, security, and social well-being, engineering practice will be challenged to shift from traditional problem solving and design skills toward more innovative solutions imbedded in a complex array of social, environmental, cultural, and ethical issues" [29].

Unfortunately, there has been a lack of attention to innovation in engineering education [7]. Except for capstone projects in their senior year, engineering students are basically trained that there is one answer to each problem. Homework and exam problems all have a single correct solution. Besides the fact that many real-world problems do not have a single answer, many real-world problems are not as well-defined as they are in the classroom and in textbooks. These ill-structured problems lack definition in some aspect [30]. While students are learning the valuable skill of problem solving, they are not learning that many real-world problems have multiple solutions. Jonassen (2000) writes, "Unfortunately, students are rarely, if ever, required to solve meaningful problems as part of their curriculum" [31]. The job of the practicing engineer is to determine which is the best solution for a given set of constraints. The best solution for one context may not be the best solution for another context. Sometimes cost, for example, may be the most important determining factor in one context while performance may be the most important in another.

Lawlor (2016) writes, "Engineering involves imagination and innovation" [32]. ABET describes engineering design as "an iterative, <u>creative</u>, decision-making process in which the basic sciences, mathematics, and engineering sciences are applied to convert resources into solutions"

[28]. However, including innovation in the engineering curriculum can be challenging. An obvious question is who will teach that subject since faculty typically have little if any industrial experience, let alone entrepreneurship knowledge and skills [33]. In addition to experience is the time to develop, supervise, and grade open-ended design projects. Industry encourages innovation because it leads to increased profitability and value. Companies that fail to innovate are often left behind, lose market share, and may ultimately go out of business. However, that is not the case in engineering education. Innovation is harder to evaluate in academia. In industry, businesses often quantify the amount of revenue generated from new products and services which can be directly measured. Teaching students to have an entrepreneurial mindset is much more challenging to assess. The longer-term measure is the productivity of a program's graduates as practicing engineers. Besides measuring innovation, it is difficult to incorporate into the curriculum, other than in capstone projects. However, it is too late in the curriculum to save innovation for the final year of a program. It needs to be taught regularly throughout the program, although not necessarily in every course.

An aspect of innovation is creativity, which can lead to significantly different and better solutions. Heywood (2005) argues that creativity is different than problem solving although they are linked [34]. Larkin (2019) notes that most problems in the engineering curriculum help students develop problem-solving skills and critical thinking, but they do little to help develop innovation skills since those problems have only one correct answer [35]. Heywood also notes the challenge of teaching creativity. A related challenge is how to measure it. A strong argument for more diverse workforces is the increased probability of getting unique and superior answers.

Where possible, instructors in Oklahoma Baptist University's (OBU's) new engineering program will give open-ended assignments where there may be multiple acceptable solutions [36]. It is easier to incorporate innovative thinking in some courses compared to others. Projects often naturally lend themselves to innovation where the problems can be more open-ended. Ideally, these projects would include a blend of theory and practical application.

Industry Partnerships

Many have called for more interaction between universities and industry but there are many challenges to these interactions [37]. For example, motivations, schedules, funding, and cultures may be very different. Some examples of collaborations include industry sponsoring visiting teacher positions, establishing visiting teaching fellowships, sponsoring competitions, and providing mentors.

There are multiple stakeholders for university programs including faculty, students, students' parents, the advisory board, and the industries that hire students upon graduation. The focus here is on the relationship between industry and academia. It has been argued here that this relationship should be a partnership because, in theory, both want the same outcome – productive graduates. Figure 1 shows an example of an effective relationship between industry and academia.

Figure 1 Relationship between industry and academic content.

Desirably, there should be a close, even symbiotic, relationship between industry and academia. Both parties should benefit from the partnership. Figure 2 shows how both parties should be positively influencing each other through a feedback loop. The relationship described here was initially primarily designed to meet employer demands in the region. Industry had significant input into the curricula and what degrees would be offered. In the longer term, it is hoped that the university will also influence industry by providing, for example, capstone and research projects that will benefit industry.

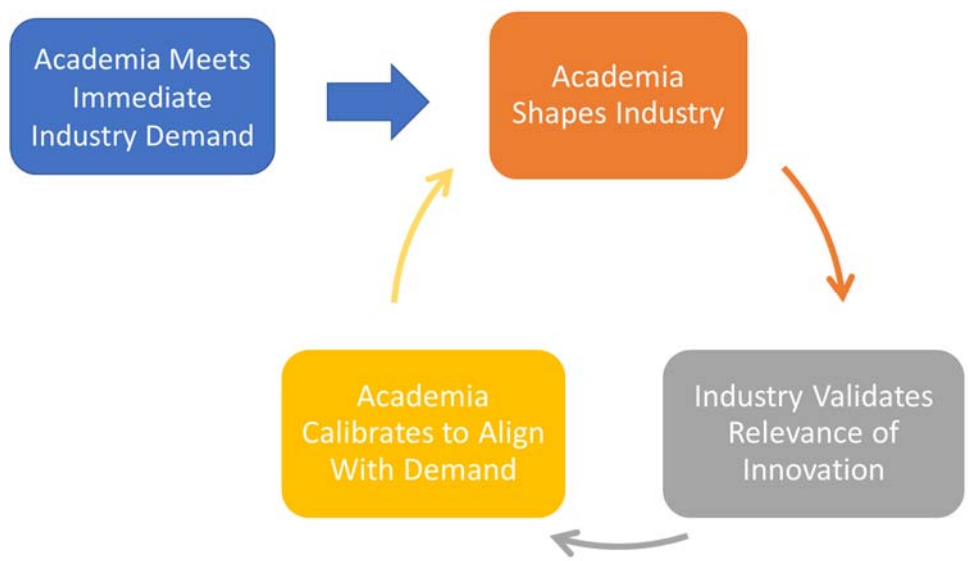

Figure 2 Symbiotic relationship between industry and academia.

There are many ways that OBU will be partnering with industry in the new engineering program. Industry will provide internships and capstone projects for students, guest speakers, adjunct instructors, and potentially hardware that can be used in labs and for demonstrations. Additionally, industry may provide some funding for the program. Besides providing students for internships and graduates for full-time positions, the university can provide, for example, seminars and workshops of interest to industry.

Education

Industry should be motivated to influence engineering education because they will be hiring the products of that education. The more effective the engineering education, the better for those organizations hiring the graduates. Conversely, universities should be motivated to produce successful graduates, which directly and indirectly improves their prestige leading to better faculty and students, larger donations, more research funding, and ultimately more demand for its graduates. Industry and academia need to work together to produce more effective graduates [38].

There are many ways that industry and universities can partner regarding engineering education. Industry can provide facility tours to show students what engineers do and the kinds of products and services they design and produce. Industry can mentor students through capstone and research projects to show them how theory is applied to real-world problems. Göl et al. (2001) strongly advocate for industry-inspired capstone projects, which better prepare students for real-world problems compared to contrived projects that are disconnected from reality [39]. Industry can provide adjunct instructors and guest lecturers who can effectively combine theory with practical applications.

Employment

One of the primary driving forces for developing the new engineering program described here is the need for more engineering graduates to work in industry in the region. Then, a key benefit of a close relationship with industry is the jobs they can provide to graduates of the program.

Industry can also provide internships and co-op assignments. These are not required in the new program but are strongly recommended. These benefit both students and employers. Internships and co-ops are, in a sense, extended interviews. Employers get an extended look at the students, typically over a summer for internships and over a semester or two for co-ops. It is difficult to judge how well a student will fit into a corporate culture based on a resume and a one-day interview. It is much easier to determine compatibility, for example, over a 2-3 month summer internship. Similarly, internships and co-ops give students a chance to see if the company is a good fit for them as well. It is certainly undesirable for a company to hire a new graduate who quits after a short time because they do not like the company, the industry, or their fellow employees. The best synergy is when the company believes the student is a good fit and the student feels the company is the type they want to work for. Previous industrial experience is a major factor when hiring new engineering graduates because employers have learned those graduates are better prepared and productive more quickly than those without industrial experience [18]. Some companies have moved to a model where they only hire new graduates who have previously interned with the company.

Advisory Board

The advisory board for an engineering program is an important stakeholder according to ABET. The board can provide useful feedback to help the program continually improve. While the program is not obligated to heed the board's recommendations, it would be a waste of a valuable resource not to strongly consider board feedback. Board members can be a source of the educational and employment opportunities previously described. A useful role for board members is to evaluate capstone projects. This gives the program feedback on strengths and areas for improvement.

If possible, it is recommended that the advisory board include a diverse membership consisting of both newer and more experienced engineers, different industries, different organization types (e.g., government, industry, education, etc.), and multiple ethnicities, genders, and experiences. Diversity helps provide a wider range of recommendations that can benefit a diverse student population. Most boards consist of both alumni and non-alumni from a program. Since there are no engineering alumni yet from the new program, OBU's engineering advisory board consists primarily of non-alumni industry members but also includes some physics alumni working as engineers.

New Program

OBU's new engineering program was started primarily for two reasons: it was the most requested degree program by prospective students that the university did not already have and the strong need in the community for more engineers. OBU initiated conversations with local employers to confirm the need for more engineers. It met with engineering directors, human resource personnel, and senior managers including company presidents. Many of the employers in close proximity to OBU are in the aerospace industry. Those employers provided nearly all of the direct feedback on the new engineering program. In addition, the state of Oklahoma has a program to incentivize new engineers entering the aerospace industry because of its goal to attract more business in that high tech industry [40]. As a result, OBU decided the new program would have an aerospace focus, although graduates can go into other industries as well.

Transfer students are accepted into the new program, but only as freshmen. When the program is fully established, transfers will also be accepted as sophomores and juniors depending on the courses they have completed.

The mission of the new engineering program is as follows:

> Industry needs engineers with integrity, critical-thinking skills, and an entrepreneurial mindset to play transformative roles in a diverse global marketplace. It is the mission of OBU's Division of Engineering to meet this demand by preparing students within a Christian liberal arts framework where faith and common sense are integrated with high academic standards throughout the learning process. All degrees will use aerospace as the context in which students are equipped.

The development of the curriculum and the important distinctives of the new program are discussed next.

Curriculum Development

Some argue that more research is recommended to develop appropriate engineering curricula [41]. This is particularly important because of rapid changes in technology. For example, 3D printers are now ubiquitous but that was not the case ten years ago. Many curricula now include the use of 3D printers as they are inexpensive and easy to use. The curricula for both new engineering programs were developed with strong input from industry. This is reflected in some of the courses, which are atypical compared to traditional engineering curricula. A few examples will illustrate this.

One of the foundation courses for both degrees is called Technical Systems, Communications, and Project Management. This is a Business Administration course that will be taught by a faculty member from that department who is certified in project management, who has a B.S. degree in Mechanical Engineering, and who worked as an engineer in industry for many years. The need for better communications instruction has been previously discussed. Industry also voiced the need for instruction in project management. They have found very few new graduates have received formal training in this important skill. While students may have learned some project management the hard way in their capstone projects, they did not learn systematic and effective methods for managing projects including both scheduling and budgeting. This course is recommended to be taken in the first semester. It should help better prepare students for their capstone projects and for working in industry.

A second required course for both degrees is called Lean Six Sigma Methods. Lean and Six Sigma are methodologies for improving efficiency and reducing defects, respectively. One's knowledge of Six Sigma is measured using karate belts. At the end of this course, which will likely be taught by an adjunct who has a Six Sigma black belt, students will have the opportunity to earn a green belt if they pass the requisite certification test. This will not only look good on a resume and set them apart from most other grads, but it will also prepare them for working in industry where those skills and knowledge are highly valued. It is recommended this course be taken in the spring semester of the sophomore year.

Another foundational course required for all engineering students is called Entrepreneurial Mindset. This was a course recommended by industry, which includes the study of the role of curiosity and the development of a value-creation mindset which are critical for innovation. Some of the specific topics include innovation, opportunity recognition, value assessment, market evaluation, and how to learn from mistakes. Important principles include taking wise risks, testing to determine feasibility, determining viability as quickly as possible, and in some cases, failing fast before spending too much time and money on an idea that is not likely to succeed in the marketplace. As one of the authors likes to tell his students, "Engineering is not about what you can technically do, but about what someone is willing to pay for." Sometimes what seem to be great ideas are either too expensive or do not satisfy a need or desire in the market and are destined to fail. This course is recommended to be taken in the fall semester of the junior year.

Distinctives

An important distinctive of the new program is an aerospace context, which meets a strong industry need in the region. All students will be required to take a course in aerodynamics. Some of the courses, such as Fluid Mechanics, will include labs related to aerospace. John McMasters from Boeing wrote an article about engineering education from an aerospace perspective [42]. He notes the need to attract new talent to the aerospace industry to both replace those who are retiring and to meet the increasing demands on new aircraft such as increased efficiency and performance with reduced pollution and noise. He argues industry, government, and academia must work together toward this goal of producing the talent needed for the industry. He believes communication between key stakeholders has not been adequate to meet industry needs. It may be argued that preparation for the complexities of aerospace also prepares students for many other industries.

Another important distinctive of the new program is faculty with significant industrial experience. Most undergraduate engineering students will go to work in industry after graduation. They need more exposure to industry while in school to better prepare them for full-time employment. Faculty with industrial experience can give students an important perspective, which is generally lacking in most traditional engineering programs. Richter and Loendorf (2007) write, “Engineers that have worked full time in industry and returned to the university to pass on their knowledge and experience bring a depth of real world case studies that they lived through” [43]. They argue that for new engineering graduates to be better prepared to meet the needs of industry, they need at least some of their engineering educators to have significant real-world experience that has been integrated into the classroom. This industry-academia partnership is expected to lead to internships for both students and faculty, capstone projects, and full-time positions among many other collaborations.

Innovation and entrepreneurship continue to grow in importance as technology advances rapidly which means those topics should be part of the engineering education curriculum [44]. Innovation can be categorized as evolutionary and revolutionary, both of which are needed. Innovation and entrepreneurship are both desirable in an industry-centric curriculum and have been included in some of the courses discussed above. As previously mentioned, projects naturally lend themselves to more innovative thinking. One of the authors incorporates an air-conditioning design project into a thermodynamics course. Teams of students each select an airplane of their choice to design its air-conditioning system. They must determine the refrigerant and the cooling load. Since this is a sophomore-level class taken by both engineering disciplines, the students are not asked to actually design the hardware, but they get a taste of real engineering because there are no single solutions. Assumptions must be made as not all data are available. That type of problem is lacking in too many courses. Also, industry-driven capstone projects typically include at least some level of innovation.

Black (1994) observes that business emphasizes total quality management (TQM), continuous process improvement (CPI), and cycle time reduction [45]. Interestingly, Black argues that changes to engineering education should not be left up to engineering faculty as none of those topics are generally taught in typical engineering programs. Alves et al. (2013) believe that teaching lean production principles can help bridge the gap between industry and academia [46]. Kanigolla et al. (2014) define Lean and Six Sigma as "two approaches used for balancing the flow of production, decreasing defects, eliminating waste (non-value added activities), reducing economic losses, and increasing customer satisfaction" [47]. They believe teaching those skills to engineering students makes them more marketable. As previously noted, one of the courses required for all students in the new program is Lean Six Sigma Methods.

The new program continues to develop close relationships with industry. For example, many industry partners serve on the advisory board. Another example is that industry is providing input on what types of software students should learn. This has many benefits both to students and to the employers that hire them. One of the important benefits of close ties with industry is that the program can maintain technical currency. These relationships with industry are easier to develop and maintain with faculty who have industrial experience themselves and speak the language of industry. In addition to academia being shaped by industry, as the academic program matures, OBU also hopes to provide training to industry to help the companies employing their students to stay relevant.

Duderstadt (2010) argues for a more liberal education for engineering students [29]. Another distinctive of the program is that all OBU students are required to take a core set of liberal arts courses. This is a nationally-recognized program that will help produce more well-rounded engineers. The acronym STEM is being replaced by a newer acronym STEAM where the A stands for *arts*. More and more companies want students with a broader perspective because today's problems and needs are broader than ever. Innovation requires thinking outside the box which means thinking beyond just engineering. Because of the required liberal arts courses, OBU's graduates are expected to have a wider field of view to meet industry's need for innovation.

Conclusions

Many have called for reforms in U.S. undergraduate engineering education for many years but relatively little has changed. Many argue current programs are too theoretical, do not teach enough on soft skills such as communication, and have little if anything related to innovation despite the strong demand for that skill in industry. OBU has developed a new engineering program in conjunction with industry, specifically with an aerospace context due to the many companies in that industry in close proximity to the university. Industry had direct input into the degrees that would be offered and into the courses in each curriculum. Courses will be taught by faculty with significant industrial experience and will include topics such as communication skills, entrepreneurship, and innovation. Students will learn not only problem-solving skills but how to solve ill-structured problems often encountered in industry. An important goal of the new engineering program is to produce graduates who become more productive more quickly because of the many topics they will have studied with direct connections to industry.

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