Appendix 2b: UMS Engineering Buildup

REVIEW OF BEST PRACTICES AND INNOVATION

Two fundamental challenges face today's engineering graduates: the exponential growth of knowledge and technology, and the globalization of the engineering workforce.[1] The quest to prepare students for these challenges is inspiring engineering educators across the country and around the world to become education innovators – questioning established practices, testing new pedagogies, and developing new programs.

This paper reviews some of the best practices and innovative techniques being developed throughout the U.S. It is not an exhaustive survey of the academic literature on engineering education. Rather, it highlights major trends and exemplary programs, reporting the results of rigorous evaluations were available.

1. Emphasizing cross-disciplinary learning

Some scholars argue that the growing number of engineering services being offered in developing countries at low cost presents a long-term challenge to the U.S. engineering community.[2] Future engineers, they argue, will have to justify higher wages with superior breadth of knowledge and capacity for innovation. Given this situation, a competitive advantage of U.S. engineering programs is their location within larger universities that allow learning and collaboration across disciplines.

Olin College of Engineering has quickly developed a reputation for innovative cross-disciplinary teaching since opening in 2002. Olin's educational philosophy emphasizes the role of engineering as a tool for solving societal challenges. "The traditional curriculum is too narrow; it teaches students how to solve problems, but not how to find the right problems to solve, or how to get their solutions out of the lab and into the world."[3] To address this shortcoming, Olin incorporates cross-disciplinary learning throughout its curriculum and programs. In their first-semester, Olin students take a foundations course in arts, humanities, and social science and a course in entrepreneurship. Although Olin is devoted entirely to engineering, its course catalogue is filled with titles such as "Engineering for Humanity;" "The Stuff of History: Materials, Culture in Ancient, Revolutionary, and Contemporary Times;" and "Identity from the Mind & the Brain: Who Am I and How Do I Know?"[4]

One example of Olin's unique approach is its collaboration with the nearby liberal-arts-oriented Wellesley College and business-oriented Babson College on an undergraduate Sustainability Certificate.[5] A core element of the program is a semester-long, project-based course in which teams of students from all three institutions design solutions for environmental problems utilizing the unique tools that engineering, business, and liberal arts bring to environmental issues.

In 1993, Stanford University's Department of Civil and Environmental Engineering embraced cross-disciplinary learning when it founded the P^5BL Laboratory (which stands for problem-, project-, product-, process-, people-based learning). P[5]BL coordinates year-long Architecture/Engineering/Construction (AEC) Global Teamwork challenges in which international teams of students design solutions for real clients.[6] Each team member has an assigned role, such as architect, structural engineer, construction manager, financial manager, or apprentice (undergraduates). The team has access to a large pool of faculty mentors and must manage their work over long distances and multiple time zones. AEC courses advance Stanford's belief that, "it is essential to educate engineers who possess not only deep technical excellence, but the creativity, cultural awareness and entrepreneurial skills that come from exposure to the liberal arts, business, medicine and other disciplines that are an integral part of the Stanford experience."[7]

2. Engaging students and industry in real-world problem-solving

Some engineering programs are promoting cross-disciplinary thinking through real-world problem solving. "Problem-based" or "challenge-based" learning presents students with difficult problems with no established solution, sometimes for the greater good and sometimes for an industry client.[8] These experiences seek to increase students' appreciation for the multi-dimensional nature of real-world challenges, including social, cultural, and financial considerations. While internships and co-ops can provide valuable real-world experiences, they are generally undertaken by individual students off-campus.[9] In contrast, having teams of students undertake real-world problems with the help of faculty and industry advisors can increase the complexity of the problem students address, create more opportunities for guided learning, and, consequently, increase the knowledge and skills students gain from the experience. Furthermore, these projects can generate explicit benefits for industry partners, a best practice for fostering long-lasting academic-industry partnerships.[10]

Some programs incorporate real-world problems in competitive challenges. The Massachusetts Institute of Technology's (MIT) IDEAS Global Challenge in an annual competition where students develop solutions to address problems facing underserved communities.[11] Successful teams receive grant money for research and prototypes and then enter a final competition for prizes of up to $15,000 to implement their solution. Recent IDEAS teams have developed apps for recovering opioid addicts and designed ambulance carts that attach to motorcycles. Some challenges are issued and funded by corporate or philanthropic partners.

At Olin College, every senior undertakes a year-long capstone project that addresses a real-world problem for a real client.[12] Students work in teams with a faculty mentor and industry advisors. There are two categories of projects – those undertaken for a sponsoring corporation and those that address a social challenge. In the SCOPE program, corporate partners provide $55,000 and an engineering problem to be tackled by the Olin students.[13] Current projects include designing robots to sort and pack items in Amazon's warehouses, helping Boston Scientific develop a new endoscope, and identifying new materials and processes to enhance Raytheon's microwave board circuitry.[14] In the Affordable Design and Entrepreneurship program, student teams work with partners around the globe on challenges facing populations in developing countries, such as designing a low-cost baby-warmer to prevent infant deaths from hypothermia and improving cassava processing machines in Ghana.[15]

Project-based collaborations are some of the most substantive and fruitful partnerships between academia and industry. Other interactions include internships and co-ops, site tours, and guest speakers. A meta-analysis of thirty-three studies of academic-industry partnerships in software engineering synthesized the best practices of these programs. They include sustained interactions, engagement by top management and senior administrators, projects based on real-world problems, and explicit benefits to the industry partner.[16]

3. Fostering professional skills

Aligning the non-academic skills of engineering graduates with the realities of the modern workplace is another dimension of engineering education that has gained attention in recent years.[17] One analyst notes, "the engineering school accreditation process has ensured the acquisition of technical competencies. Rather, engineering majors who fail in industry are those who have all the right technical competencies but not the soft or people skills to be successful."[18]

Workplace skills are both interpersonal and intrapersonal. Interpersonal skills – often called "soft skills" – are critical for building relationships and working in a team. These include knowing how to communicate effectively, interview well, and be culturally sensitive. Many of the team-based activities described above cultivate these skills. Intrapersonal skills like creativity and perseverance are harder to define but research suggests these traits are essential for students to succeed in college and the workplace.[19]

Iowa State University's engineering department determined that the best place to evaluate students' workplace skills is in co-ops and internships, and the best evaluators are the students and their supervisors.[20] Through a process that involved input from 212 employers, alumni, faculty, and students, they identified fourteen workplace competencies ranging from engineering knowledge and quality orientation to cultural adaptability and integrity. Following an internship or co-op, students and their supervisors complete an on-line evaluation that assesses students' mastery of the fourteen competencies (the evaluations are mandatory for students to receive credit).

The University of Texas at El Paso College of Engineering has elevated engineering leadership to an undergraduate major. Engineering students in the program develop skills and knowledge in the program's three pillars: character, competence, and capacity (adapted from the U.S. Military Academy at West Point).[21] One innovative aspect of the program is a required non-credit class for first-year students called Introduction to Engineering Leadership that is designed and taught by second-year students.[22] Putting students in charge of the course creates an opportunity for them to practice leadership skills, and faculty members credit student instruction with helping to increase the program's retention rate from 30% to 70%.[23]

Massachusetts Institute of Technology's Undergraduate Practice Opportunities Program (UPOP) is a year-long development program that helps sophomores hone the professional skills needed for career success.[24] It provides workshops and coaching on resumes and cover letters, interviewing, networking, negotiating, and communication. The program takes place during students' sophomore year so they can use those skills to acquire internships and other work experiences that will position them for career success by the time they graduate.

4. Engaging first-year students

Research

Historically, hands-on research often came at the end of a student's undergraduate career as a capstone experience that built on the foundational knowledge they had acquired during the first few years of study.[25] While this is a logical progression, engaging students in research experiences sooner has been found to increase retention. The University of Central Florida's Learning Environment and Academic Research Network (LEARN) program pairs first-year engineering students with graduate-student mentors to experience hands-on research for a minimum of 3-hours per week. The first two cohorts of LEARN students have exhibited long-term increases in retention and GPA. By the end of their second year, 75% of LEARN students remain in a STEM field compared to 49% of non-LEARN students in control groups.[26]

Olin College of Engineering has embraced first-year research by incorporating hands-on projects into three required courses that students take in their first semester. Likewise, MIT freshmen are immediately eligible for its Undergraduate Research Opportunities Program, which allows them to assist MIT faculty members conducting original research.

Learning Communities

Many colleges are experimenting with "learning communities" – groups of first-year students who take two or more classes together, sometimes with the same instructors and/or support staff. The goal is to help students make strong social connections and engage more deeply with course material during their critical first semester of college. Research at the University of California Fullerton shows that students who participate in Freshman Learning Communities have higher retention and graduation rates than those who do not, even accounting for high school GPA, and the communities especially benefited minority students.[27] Olin requires all students to take the one-credit course "Olin Introductory Experience" aimed at ensuring their successful transition to the college.[28] Some engineering programs, such as Drexel University's, offer living-learning communities where new engineering students can live in the same residence hall as other first-year students in their major.[29]

5. Re-examining classroom pedagogy

In 2012, the American Society for Engineering Education (ASEE) noted the need for the engineering community "to raise its awareness of the considerable educational infrastructure that already exists, both within and outside engineering, and the substantive body of knowledge of proven principles and effective practices in teaching, learning, and educational innovation."[30] ASEE called for engineers to value educational innovation within their field as much as technological innovation.[31]

In that spirit, the following section highlights some of the best pedagogical techniques being used by engineering programs across the country. Many of them focus on improving student outcomes in the introductory courses that often serve as gateways to the major. These new techniques are illuminating the role of pedagogy in student performance and retention.

Active Learning

A large and growing body of research suggests that traditional college lectures are not the most effective way to increase student knowledge. In particular, researchers are comparing the results of tradition learning characterized by "continuous exposition by the teacher" and active learning that "emphasizes higher-order thinking and often involves group work."[32] A recent meta-analysis of 225 studies compared the performance of college students in science, technology, engineering, and mathematics (STEM) courses that utilize those techniques.[33] The researchers found that students in traditional-learning classes are 55% more likely to receive failing grades or withdraw from the class than students in active-learning classes.[34] The findings held true across all STEM disciplines and class sizes.

Flipped Classroom

The rise of active-learning techniques coincides with another new practice – the "flipped classroom." The term generally refers to teachers delivering lectures via prerecorded videos that students watch as homework, which frees up class time for group- and discussion-based learning. While there is little rigorous, comparative research on flipped classrooms, what exists suggests the potential for positive effects on student performance and engagement.[35] In addition to increasing students' content knowledge, this technique increases the need for them to come to class prepared. The University of Texas at El Paso's Bachelor of Science in Engineering Leadership program uses this technique as "…one of the many ways the program promotes leadership of the self."[36]

Peer instruction (PI) is a flipped-classroom technique popularized at Harvard University in the 1990s. Instructor uses real-time technology to gauge students' responses to questions on the content of pre-class readings and assignments. If a concept is well understood the instructor moves on. If not, students have a few minutes to discuss the topic with each other and re-answer the question. This technique has been found to deepen students understanding and engagement with course material and their classmates. One study compared the results of PI and traditional instruction of a year-long introductory physics course. Students in the traditional course were twice as likely switch to a non-STEM major the following year as students in the PI course (11% versus 5%). [37]

Integrated Learning

Integrated learning seeks to increase student engagement and deepen content knowledge by teaching foundational engineering concepts in an integrated manner, rather than in isolation. Responding to low enrollment and retention rates, the Colorado State University's Department of Electrical and Computer Engineering embraced integrated learning during a comprehensive redesign of their pedagogy, curriculum, and organizational structure funded by a five-year grant from the National Science Foundation.[38] They concluded, "the crux of the problem [of high attrition rates] lies in the failings of the traditional course-centric structure wherein faculty function independently without demonstrating the connections between fundamental topics throughout the… curriculum."[39]

The department broke apart some of their core courses and rearranged them into “Learning Studio Modules” that teach concepts in an integrated manner using real-world engineering problems. The department incorporated flipped-classroom elements into its teaching; students must complete pre-work and online evaluations prior to beginning the modules. Finally, the department re-imagined faculty roles by assigning faculty members as “integration specialists” responsible for interweaving skills and concepts throughout the department’s curriculum and activities, rather than delivering them as individual components taught in silos. The department is still implementing this redesign but early results are promising. From Fall 2015 to Fall 2016, the numbers of students receiving Ds or Fs in core classes fell by half.[40]

Conclusion

There is ample innovation occurring within the U.S. engineering community to inspire and guide growing programs. While the long-term impact of some initiatives is impossible to know, studies of short-term impacts suggest that student-centric, project-based, real-world learning experiences have the potential to enhance student outcomes and retain more students in the field.

Endnotes

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