New STEM and Engineering Education Paradigms

Two recently released reports [1], [2] provide some critical perspectives and recommendations for change in the way that we teach science, technology, engineering, and math (STEM) to both undergraduate and graduate students. These reports also provide plenty of insights into the new ways that some institutions are structuring engineering-related degree programs and how those changes are being positively viewed outside those institutions. These insights will provide guidance to academics on positive changes that can be made to their undergraduate and graduate degree programs and to members in industry on what new skill sets to look for in the graduating workforce.

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UNDERGRADUATE EDUCATION

The report [1] was sponsored as part of the New Education Engineering Transformation (NEET) at the Massachusetts Institute of Technology (MIT) to analyze the state of the art in the worldwide undergraduate engineering education. The approach interviewed approximately 180 individuals with in-depth knowledge of the leading engineering programs. The discussion proceeded in two phases. Phase 1 focused on identifying the cutting-edge global engineering education programs, and Phase 2 included in-depth case studies of four programs identified in Phase 1 as "emerging leaders." Using the information gathered from these interviews, the overall goal of [1] was to answer the following questions:

1) Which institutions are considered to be the "current leaders" in engineering education?
2) Which institutions are considered to be the "emerging leaders" in engineering education?
3) What features distinguish the current and emerging leaders?
4) What key challenges are likely to constrain the progress of engineering education in the future?

With the disclaimer that my own institution (MIT) figures prominently in the answers to questions 1 and 2, the survey as a whole yields some surprising insights into the state of global education in engineering.

The responses to question 1 yielded five institutions that were most frequently identified as "current leaders" (see [1, Fig. 4]), including MIT (United States), Olin College (United States), Aalborg University (Denmark), TU Delft (The Netherlands), and Stanford University (United States). Four of these are well established, but for those that don't know Olin College, it was founded in 1997 just outside Boston "to radically change engineering education with the goal of fueling the technical innovation needed to solve the world's complex future challenges" [3].

The ten most frequently identified as "emerging leaders" in the responses (see [1, Fig. 5]) included Singapore University of Technology and Design (Singapore), Olin College, University College London (UCL, United Kingdom), Pontificia Universidad Católica de Chile (Chile), Iron Range Engineering (United States) [4], National University of Singapore (NUS, Singapore), TU Delft, Charles Sturt University (CSU, Australia), Tsinghua University (China), and Arizona State University (United States).

These lists (further details are provided in [1]) lead to some key observations. First, there is a "shift in the center of gravity of the world's leading engineering programs" from the north to the south and from high-income countries to emerging economies in Asia and South America. A second trend identified is that there is a move toward socially relevant curricula. In particular, many of the emerging leaders

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provide experiences in this area that are fully integrated with the technical work, as opposed to being the isolated, "bolted-on activities" that are typically found in the "current leader" programs.

The third trend is the emergence of student-centered curricula, with a focus on combining the learning of technical skills with the contextualization of those skills through design projects. In the discussion of "How should educational quality be measured," [1, p. 13] the author also noted that there was clear consensus that "measuring the impact we have on our students, how much they are actually learning, is something that we as a community do very badly." It was noted that Aalborg University was repeatedly cited as the exception, and thus its approaches to measuring educational impact could be considered as a best practice that should be carefully considered by others.

The four cases studies in Phase 2 provide further details on how these emerging leaders are creating innovative learning experiences for students. For example, since 2014, UCL has adopted a new curriculum centered around "scenarios," which are a sequence of five-week cycles that involved four weeks of building key engineering skills that are then applied in an intensive one-week design project. This Integrated Engineering Program (IEP) focuses on multidisciplinary learning, applying knowledge to practice, developing the students' professional skills, and the "framing of engineering as a vehicle for positive world change" [1]. These goals are not unique to UCL. However, integrating this IEP education across the core curriculum for thousands of engineering students in eight departments certainly sets the university apart from its peer institutions. CSU accomplishes a similar objective by combining an 18-month, on-campus education centered around project-based learning with four years of off-campus, work-based learning. In that case, nearly all advanced technical materials are delivered online to students working remotely, as needed.

Some of the approaches developed by the emerging leaders have completely redesigned their curriculum from what was essentially a blank slate. In contrast, TU Delft appears in both lists in recognition of its continued ability to maintain academic rigor and yet apply small changes that enable new educational innovations (such as a pioneering approach to both on- and off-campus blended and online learning) to be adopted. Key to this development has been the educational leadership and a decentralized environment that provides sufficient freedom to implement new initiatives.

MIT is using the input from the report as part of the guidance to create the NEET program (I am the lead for the effort within the autonomous machines) that will focus on project-based learning. However, NEET is just starting, and the population within the autonomous machines thread is still quite small (the second-year class will be approximately 40 students). Therefore, a challenge faced by MIT is how can this type of new engineering education be offered at a large enough scale to impact more students? The UCL, CSU, and TU Delft examples illustrate that innovative solutions are being developed to address these challenges, and the approaches developed are being recognized as setting new benchmarks for excellence in engineering education. The goals of these educational programs and the frameworks developed to implement them could provide excellent guidance for other engineering schools that have the flexibility to implement similar, large-scale changes in their curricula.

GRADUATE EDUCATION

The panel that wrote [2] was convened in response to recent survey results that indicated, "Many graduate programs do not adequately prepare students to translate their knowledge into impact in multiple careers." Reference [2] outlines a vision for the "ideal graduate student education" in STEM, with one of the key recommendations being that there be a shift away from the current graduate educational system (focused on the needs of the institution and the associated research efforts) toward a paradigm that is more *student focused*. This includes providing opportunities for students to communicate their work and understand its broader impacts, encouraging them to create their own project-based learning opportunities, giving students time to explore diverse career options, and helping them identify advisors and mentors who can best support their academic and careers development. The extensive report (see [5] for a shorter discussion) provides 12 detailed recommendations for revitalizing graduate STEM education for the 21st century, which can be paraphrased by the comment [2, p. 55] that the report "recommends a cultural change in the nation's universities that puts students at the center of the graduate student experience."

These two reports focus on different aspects of the educational experience, but there is quite a bit of commonality in the recommended changes, which should give some food for thought for those with the flexibility to revise their undergraduate and graduate STEM programs. It is also clear that these changes are already underway at some institutions, which will raise the bar on what is expected at others. Therefore, if the flexibility to make those changes does not currently exist, now might be a good time to determine how to create it.

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