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RESTRUCTURING ENGINEERING EDUCATION: Why, How and When?

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ABSTRACT

There is strong interest in broadening engineering education, bringing in more liberal arts content as well as additional subjects such as economics, business and law, with which engineers now have to be familiar. There are also cogent arguments for balancing against what is now the almost exclusively quantitative nature of the curriculum, adding more elements that relate to the actual practice of engineering, and structuring engineering education so as to provide multiple and later entry points, which should enable more informed career choices and make engineering attractive to a more diverse range of the population. Many have also sought a change in the level of the professional engineering degree from the bachelor's to the graduate level, which would logically, and probably also necessarily, accompany these changes. However, progress towards such changes in the United States has been marginal, in large part because incentives on the micro- and meso-scales do not match those on the macro-scale. On the other hand, there is much more substantial change in other countries, driven in part by the Bologna process. For the United States to be the last to change would be counter to the goal of retaining higher-functioning engineering jobs in the U. S. What needs to happen in order for the U. S. to change is evaluated.

The Need for Structural Change

There have been many recent calls for much greater breadth in undergraduate engineering education and for enabling entry points to engineering at later stages of education, often coupled with recommendations that the professional degree should be moved to the graduate level. These calls include a major National Academy of Engineering (NAE) study[i]; an in-depth report by Duderstadt[ii]; the 5XME Workshop within mechanical engineering[iii]; and articles by Augustine[iv], Wulf[v], Wenk[vi], Katehi and Ross[vii], Grasso and Martinelli[viii], Grasso, et al.[ix], Mills and Ottino[x], and King[xi], among others. As well, there have been cogent arguments for integration of much more material and opportunities relating more directly to engineering practice throughout the curriculum, most recently put forward by Sheppard, et al.[xii] in a study for the Carnegie Foundation for the Advancement of Teaching.

Essential Arguments. The essential arguments that have been put forward in these studies and publications are the following.

Among the larger professions, engineering is the only one for which the bachelor's degree is the primary accredited, professional degree. By contrast, medicine, law, public health, business, architecture and other major professions have graduate-level professional degrees built upon the base of a liberal undergraduate education. Since the entire professional program is concentrated into the undergraduate degree, engineering education has little room, if any, for much needed breadth. As well, the one-dimensional and almost exclusively rigorous, quantitative aspect of undergraduate engineering education reduces the spectrum of the population to which it is attractive. Many believe that the fact that still relatively small numbers of women and minorities are drawn to engineering is attributable to this ultra-quantitative focus, as well as to the lack of evidence of the social impacts of engineering in the early engineering curriculum[xiii,xiv], and there is good evidence to support that conclusion[xv,xvi,xvii].

The world has evolved and continues to evolve in ways that proponents of change believe make it imperative for engineering education in the United States to evolve simultaneously. For example, the economic realities of global competition and the arrival of ubiquitous broadband communications are driving entry-level and more routine engineering jobs overseas to countries

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such as India and China. American engineers need additional dimensions of knowledge in order to compete and for the United States to retain its role as the world leader in technological innovation. Business continues to become more international, increasing the need for engineers to understand other cultures and societies. To advance, branch out and be most effective during their careers, engineers need to master much beyond the concepts of engineering itself.

It is also well recognized that it is essential to diversify the engineering profession further in order to sustain it in the United States. Three avenues for facilitating greater entry of ethnic minorities and women to the profession are providing greater breadth, enabling more flexible and later entry points into engineering education, and provision of courses early on that illustrate what engineers actually do. Greater breadth will attract potential majors who currently see the choice as being between engineering and having a "normal" college education. More flexible entry points will enable the final choice of engineering as a major to be deferred until a later time. Today the choice towards a technical career must be made early in high school or even in junior high school in order to avoid substantial delays. We need instead to enable the choice to be made at points *during* an undergraduate college career. The community college transfer path is a potentially rich source of diversity and should be made more attractive to students and more workable. More flexible and later entry points will help that route. Finally, it is important that the early part of the curriculum illustrate what engineering actually is, and for fundamentals to be integrated with elements of engineering practice throughout the curriculum[12]. All these factors call for more breadth and flexibility, and concomitantly also a move of the actual professional degree to a level past the baccalaureate.

Among the specific needs that most of the proponents believe should be met by broadening engineering education are:

- more understanding of the human condition, cultures and society,
- ability to work effectively with public policy, business and government needs,
- an understanding of the process of innovation and factors contributing toward it,
- ability to work in synergy with persons from other disciplines, including both other science and engineering fields and non-science/engineering fields such as business, law, economics, public policy, sociology, and others,
- ability to communicate and to express technical issues in simple, understandable terms, and
- general liberal education, integrated with engineering education.

The Association of American Colleges and Universities (AAC&U) defines liberal education as:

> "an approach to learning that empowers individuals and prepares them to deal with complexity, diversity, and change. It provides students with broad knowledge of the wider world (e.g., science, culture, and society) as well as in-depth study in a specific area of interest. A liberal education helps students develop a sense of social responsibility, as well as strong and transferable intellectual and practical skills such as communication, analytical and problem-solving skills, and a demonstrated ability to apply knowledge and skills in real-world settings."[xviii]

That definition embodies most of the elements of breadth that are sought. An additional point, however, is that in the present way of doing things the typical student will, on his or her own, have to integrate the liberal education experience with the engineering education experience. Engineering faculty need to participate in the broadening process by showing how the engineering subject matter interacts with a variety of human concerns, in short with social science, humanities, and other professions.

Progress toward Change in the United States

There are some early signs of progress towards these goals, but they are limited. The profession of civil engineering has had a long-term project that has involved development of an identified "Body of Knowledge", plus the requirement of education beyond the bachelor's degree for licensure[xix]. While it is also directed toward increased breadth, this effort has primarily dealt with increased technical knowledge. Partly in response to the civil engineering effort and the National Academy of Engineering study[1], the engineering accrediting agency ABET has recently removed the restriction that accreditation can be given at only one degree level. Earlier, ABET had added some broadening criteria to its accreditation standards for bachelors degrees.

Newer programs at Smith College, Harvey Mudd, and Olin College have important elements of change. The partnership between the University of Illinois and Olin College[xx] is evidence that attention is being paid to these programs by some larger institutions. The undergraduate degree at Smith is a liberal arts degree, accredited for general engineering but not the individual engineering disciples. It successfully prepares students for graduate programs in the individual engineering disciplines.

At Harvard and Yale the situations and degrees of attention to engineering have long been subjects of controversy, relating to whether there is a proper role for engineering in a liberal-arts college. Now, engineering is being rebuilt within Harvard College and Yale College, and is subject to the breadth requirements of those Colleges. Three classes of bachelor's degrees in engineering are offered at Yale, with different ratios of technical courses to liberal education courses – an ABET-accredited Bachelor of Science, a Bachelor of Science in Engineering Sciences, and a Bachelor of Arts in engineering Sciences.[xxi]

Resistance to Change

Despite these positive steps, overall progress towards broadening engineering education and/or transitioning towards the graduate level for the professional degree in the U. S. has been, on the whole, very small. In the engineering fields other than civil engineering it has been virtually non-existent. Why has there not been more change? There are several key factors.

- Industry has largely been very willing to hire engineers at the bachelor's level. The fit has been to current entry-level jobs, and the lower salary for a bachelor's graduate as opposed to an advanced degree holder has been an attraction to employers. This is, however, a situation where the career interests of the individual engineer diverge from the interests of most entry-level employers. An engineer with a broader education should have more opportunities for upward advancement, career development and evolution. Overall, more broadly educated engineers should enhance innovation and competitiveness, which is of strong public interest. There is much more interest on the part of industrial CEOs, e. g., Augustine[4], in longer and broader engineering education than there is from entry-level recruiters.

- The culture and traditions of universities are such that changes in academic programs come bottom-up, not top-down; i.e., they are defined by the faculty of academic departments. There are many engineering faculty members who do not yet recognize needs for change, and even those who do recognize it have to contend with the intense and multi-dimensional pressures stemming from the many aspects of their jobs. The prevailing academic culture, including the academic reward system, encourages emphasis on research, scholarship and in some cases high-level professional activities. Change poses added pressures, is time consuming, and creates the need to develop new curricular approaches and courses. Faculty members have generally preferred to stay with the *status quo*.

- There is a cost for further education and a consequent need for additional financial aid, which is currently less available at the graduate level for curricula that are not research-based.

Viewed another way, there is not a good alignment between the interests of those who would benefit from changes of this sort in engineering education (the public and students) and the interests of those who have the primary determining influence over such changes (faculty and entry-level employers, and through them most professional societies).

What is Happening in Other Countries?

There are important changes abroad that are occurring on a broader scale than just engineering, but which strongly affect engineering. In Europe the Bologna Process is working toward a uniform structure of a three-year first-cycle, or bachelor's, degree, which can then be followed by a two-year, second-cycle master's degree[xxii]. (In considering the number of years, it should be recognized that there is typically one more year of secondary education in Europe than in the United States.) This structure forces the issue of considering the appropriate professional degree for engineering[xxiii], with the greater body of thought now seeming to be that the second-cycle degree should be the professional degree[xxiv,xxv] In Germany and France and other countries based upon their models this relates in part to the pre-existing degree structures, which required as much as seven or eight years of university education.

The United Kingdom and Ireland have now adopted the Master's degree plus some experience as a requirement for achieving the status of Chartered Engineer, and university degree programs have responded accordingly[xxvi,xxvii,xxviii].. In most or all of these cases in Europe the baccalaureate is a technology or pre-engineering degree rather than a conventional liberal education.

Similar thinking is spreading to Australia[xxix] and other countries, including China and India. For the national universities in Japan, the professional degree is now usually the Master's degree, especially in the national universities[xxx,xxxi]. The University of Melbourne in Australia has recently gone a step further and has instituted the "Melbourne Model", which provides a limited choice among only six different broad majors at the bachelor's level, followed by more specialized and/or professional master's degrees[xxxii]. The master's thereby becomes the engineering professional degree[xxxiii].

The Path of Least Resistance

Left alone, much of the rest of the world will probably turn toward the professional engineering degree being at the graduate level before the United States changes in that direction. Reasons are the Bologna process and its outfall, the roles of ministries, and the fact that the rest of the world does not have the degree of complacency that the U. S. seems to have with regard to the structure of engineering education. As was already noted, the Bologna process and the attention that other countries are paying to it forces a reexamination of the appropriate level for the professional degree. The Bologna declarations with respect to degree structure give a structure much like the U. S. degree pattern. Thus U. S. universities have not felt affected by the Bologna process. Ministries in many other countries have strong, influential and even determining roles with respect to degree structure. There are no comparable bodies within the U. S.

For much of the rest of the world to convert to professional degrees in engineering that are at the graduate level before the U. S. converts would stand in contradistinction to the U. S. goal of providing a more highly functioning engineer and thereby keeping the primary locus of technological innovation within the United States. Since the rest of the world is changing, the United States must give more attention to change now.

How the United States Could Change More Actively

Background**:** There are other professional fields that have made similar changes in their degree structures in the past. Following the influential Flexner report[xxxiv] of 1910, the field of medicine was transformed in the early twentieth century from highly varied preparation, often with little liberal education or even no undergraduate basis, to a graduate-level (M. D.) degree based upon a liberal undergraduate education. Law underwent a similar change at about the same time that medicine did but in a less directed way, resulting in the J. D. being built upon a liberal-arts undergraduate education. Pharmacy in recent years has switched from the bachelors to the doctorate as the professional degree. Audiology and some other specialized fields are currently undergoing or attempting to undergo transitions from the masters to the doctorate as the professional degree. Unfortunately, all of these transitions had specific features and circumstances that seem not to be particularly germane to the present situation for engineering.

There have been some recent projects directed toward understanding how change can be achieved in less comprehensive ways in engineering education, e. g., with regard to individual curricular changes and teaching methodology made in response to scholarship on engineering education[xxxv,xxxvi,xxxvii]. These provide some useful insights.

Possible Avenues**:** The default situation for the United States is that enough of the rest of the world will change by adding breadth and putting the professional degree at the graduate level so that the United States will have to change in response. As noted above, that is not a desirable scenario. But what are possible ways in which structural change for the United States could be accelerated? The following are some possible motivating forces.

- *Faculty choice within individual institutions***.** If faculty one or more leading engineering programs would adopt greater breadth and movement of the professional degree to the graduate level, that would provide a considerable boost. However, there are disincentives to going first. One way of doing this with less disincentive would be for more programs to choose to follow the example of successful innovative programs, such as Smith, Yale or Olin.
- *Structural transitions at the level of an entire university, e. g., the Melbourne Model, which force reconsideration of the engineering degree structure.* This begs the question of how many universities will undertake such major transitions. The funding crisis for public universities and some private universities in the U. S. make this more of a possibility than would otherwise be the case. Universities have to reevaluate their academic and financial models.
- *Redefinition by a number of employers of desired pre-employment education***.** This process could be helped by CEOs and other concerned high-level officials propagating their desires downward to recruiters and to members of industrial corporations who are on advisory boards to engineering schools and departments.
- *Further influences from the National Academy of Engineering and other high-level sources***.** The Academy has the bully pulpit, and its report on Educating the Engineer of 2020 has already garnered significant attention.
- *Leadership by individual engineering professional societies and ABET.* Individual engineering societies can lead their own branches of engineering and influence ABET, in ways that have been pioneered by the civil engineering profession. Alternatively ASEE and ABET themselves could chose to lead.

What is needed in any event is a critical mass of opinion supporting change. That can occur with continual attention to the subject at professional society meetings, through publications and through personal contacts.

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