ECE as a Pre-Professional Undergraduate Program

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Abstract

Rapid changes and broadening scope in electrical and computer engineering combine with other pressures to make BS-level preparation for the future difficult. One logical solution is a pre-professional degree, focusing on broad educational outcomes and featuring nontraditional learning experiences, leading to a variety of graduate school career tracks.

Introduction

During the last part of the 20th century, the field of electrical engineering evolved into a multiplicity of fields barely related to one other. The breadth of work accomplished by electrical and computer engineering (ECE) professionals now encompasses such widely disparate areas as cryptography, autonomous robotics, nanotechnology, wireless networks, superconducting electric power systems, organic electronics, Web software, photonics, and embedded speech recognition. Given that the fields of ECE are certain to change further, in directions difficult to anticipate, how can undergraduate programs possibly provide the breadth and depth to prepare students for success and leadership?

In this paper, the authors will argue that trends in higher education will combine with changes in technology and demands on the engineering profession to effect a fundamental change in undergraduate study of ECE: the move toward pre-professional education. The 4-year bachelor’s degree will prepare students for graduate study in preparation for a wide range of careers by focusing more broadly on general education outcomes and by employing new learning activities. By moving away from the content-
driven course/lecture model to more varied learning experiences, including open-ended research projects, service learning, and study abroad, engineering programs can provide the basis for lifelong learning and leadership in technological innovation.

**Trends in Interest in Engineering**

The profession of engineering suffers from relatively low popularity among entering first-year college students, and the relative popularity has been decreasing in the recent past. BS-level engineering degrees awarded annually in the U.S. reached their highest level in 1985, with 77,572 BS degrees awarded [1]. By 2000, that number had fallen to 59,536, a decline of 23 percent. For electrical engineering degrees, the decline has been even more dramatic. The peak was reached in 1987 with 26,791 degrees while in 2000 17,672 EE degrees were awarded, a drop of 34 percent. Further, the engineering majors suffer from very low and stagnant or declining popularity among females. The electrical engineering BS degree numbers for females in 1987 and 2000 were 3,564 and 2,350, respectively. Engineering enrollment numbers show the same trend as degrees, decreasing from a high of 441,000 students in 1983 to a level of 356,000 students in 2001 [2,3]. Engineering is historically cyclic, and is impacted by the dramatic boom and bust hiring activity brought on by economic cycles and changes in technology. However, the seriousness of the present downward trend is highlighted by the fact that no reversal in slope occurred during the high tech boom period of the late 1990s.

In the past, engineering was seen as a secure, relatively well-paying profession which a BS graduate could enter without further study, at the expense of a relatively intense and difficult undergraduate program. Now, however, with more career options,
other professions featuring graduate preparation, and lowered prospects of secure longterm employment, the attractiveness of the traditional engineering program is diminishing. Furthermore, the perception of engineering as a narrow field disconnected from social relevance and human need is a likely barrier to many students, especially women. The time has come for a fundamental change away from technical training toward an undergraduate education more like that of other professions. With a range of post-BS professional programs and career paths, the decision to select an engineering major would no longer be based solely on the hope for a favorable engineering job market four years later. If potential students understand that their options include fields such as law, business, medicine, and education, the possibility of a downturn in the need for entry-level engineers will seem less ominous. In order to accomplish this, though, engineering education needs to appropriate some ideas from outside the engineering community.

**Change in Engineering Education and in Higher Education**

Regardless of the rapid changes in the engineering profession, colleges and universities have remained places where change tends to occur at a much more deliberate pace. The changes that do occur in engineering curricula are more often marginal—replacing existing course content with newer course content—rather than fundamental. However, a confluence of additional pressures, including new accreditation criteria, demands for accountability in higher education, the need to attract a larger and more diverse student pool, the commoditization of education via distance learning, and the changing needs of the US and global economies, suggests that a time of fundamental change in engineering education may be imminent. Senior capstone
design projects, integrative work for first year students, and engineering courses that focus on communication, teamwork, and professional skills, are becoming more common, and more engineering programs are encouraging study abroad.

These trends reflect signs of transformative change in higher education in general, and are supported by discoveries from the past 20 years about student learning (c.f. [4]) and its relationship to the college experience (c.f. [5,6]). The research underpinning the National Survey of Student Engagement [7] and the findings of National Panel Report [8] from AAC&U’s Greater Expectations project suggest a clear move toward what might be called “new forms of learning”: project-based learning, integrative learning, study abroad, service learning, learning communities, undergraduate research experiences, capstone experiences, peer learning, and other nontraditional learning experiences and environments.

These new forms of learning represent an important departure from curricular models based solely on courses, lectures, discussions, and laboratories. They are based on the premise that the best way to prepare students for successful careers and lives is to engage them as active and deliberate learners, immersed in experiences that more closely resemble the world outside academia and allow students to bring their knowledge to bear on real-world situations. Rather than being defined by content to be “covered”, these experiences are more likely to focus on processes and on learning outcomes: the skills and competencies that students will acquire.

**Implications for Engineering Education and Educators**

The new forms of learning that emerge as examples of good practice focus on outcomes defined in terms of student learning, and encourage development of broad
skills, such as critical and integrative thinking, communication and teamwork, and the solution of unscripted, open-ended, real-world problems. These, of course, are precisely the skills called for in engineering by the National Research Council [9] and ABET [10].

To incorporate the new forms of learning in ECE curricula, courses and lectures must give way, in part, to accommodate more varied learning environments and experiences. This will necessitate changes in the role of the faculty member who, in addition to being an expert resource of specific disciplinary knowledge, must become a facilitator of learning, a coach and mentor; such changes have significant implications for faculty training and development.

Changes in how engineering faculty are prepared, hired, and evaluated will certainly be evolutionary, rather than revolutionary. Nonetheless, the work that they do is likely to change at an aggressive pace, mirroring the rapid changes in technology that they already are used to negotiating. However, for ECE programs to accommodate broader learning outcomes, the expectations of students and of the industries and graduate schools that they seek to enter must also change.

**Push Comes to Shove: The Pre-Professional ECE Degree**

ECE education finds itself in the middle of several sets of competing demands: students’ need for broad education vs. engineering’s requirements of depth; the long-term career prospects of students vs. the short-term needs of employers; the decline in student interest vs. social and economic needs for a technologically competent citizenry. The increasing complexity of engineering practice requires system-level thinking and implementation, yet curricula typically build from the device and
phenomenon level upwards. Students and employers often want a focus on cutting edge tools and technologies, a demand subtly reinforced by graduate schools’ training of future faculty and by academic reward systems that encourage a great degree of specialization. On the other hand, there is an increasing recognition of students’ need to learn how to learn and think, and to build a broad foundation on which they can construct productive and satisfying careers in the midst of technological, social, and political changes that will bring constant cycles of obsolescence and renewal.

One potential solution would be a 5-year program—most European engineering programs already do this—but no coalition of US universities willing to take such a risk has emerged to set the trend. Perhaps more significantly, a fifth year would add 25% onto what is already an extremely expensive education to deliver and to receive. Instead, the solution proposed here considers the three traditional roles of the residential undergraduate program—student maturation, general education, and professional or pre-professional education—and concludes that since engineering is a profession requiring broad education and disciplinary depth, it is time for US engineering education to structure itself to recognize that fact and make the BS degree explicitly pre-professional, leading to various graduate school tracks prior to professional practice.

Two common fields requiring a pre-professional bachelor’s degree are law and medicine. Engineering, it can be argued, is different in a subtle and important way, since in addition to being a profession it is also an undergraduate academic discipline. Thus, the pre-professional degree would itself be in engineering. It can be argued that the BS in engineering has been in the process of this transition for some time, since an
increasing number of engineering positions require graduate study. Certainly, given the breadth of ECE, the pre-professional degree may take different forms: BS in computer engineering, BS in math/signal processing, BS in physics/physical electronics, BS in physics/nanostructures. Regardless of whether it takes multiple or single forms at a given university, it would include a substantial amount of general education and a strong engineering design content in the form of projects and other new forms of learning, and avoid overspecialization or overemphasis on the latest tools and technologies.

The civil engineering profession is taking the lead on this issue. In 2001, the American Society of Civil Engineers (ASCE) approved a policy stating that “ASCE supports the concept of the Master's degree or equivalent as a prerequisite for licensure and the practice of civil engineering at a professional level.” [11] The supporting report identifies four driving factors behind the inadequacy of the 4-year bachelor’s degree:

- “Narrow formal education of civil engineers, providing inadequate preparation for a rapidly changing work environment, for changing production and delivery systems, and for leadership roles.
- Gradual historic reduction in credit hours required for the BSCE degree and ‘slippage’ in the civil engineering education-experience-licensing-certification-continuing professional development process relative to other professions.
- Low compensation received by civil engineers relative to other engineering disciplines and other professions.
- Declining appeal of CE to highly motivated young people.” [13]

With the exception of the third item, all of these statements apply to ECE. While compensation of electrical and computer engineers is at or near the top of the
engineering profession, job security ranks at or near the bottom. This must represent an impediment to selection of ECE as a career. While implementation of the civil engineering vision is based more around licensure issues, much of the underlying reasoning is applicable across the engineering professions.

Who will pay for the professional-level MS degree? The economics are different undergraduate education, since most fulltime graduate students can be said to work for the university. Funded research in areas of strategic importance to government and industry will be a key source of support. A better-educated engineering workforce may require greater investment from industry than graduate programs currently enjoy; incentives for this type of investment may be necessary.

The Pre-Professional ECE Curriculum

Traditionally, engineering programs have required more credit hours than other undergraduate majors, in an obvious attempt to include sufficient amounts of both general education and engineering content. With the increase in disciplinary knowledge and the pressure to reduce graduate requirements, the old approach is simply no longer tenable. The proposed program would be based on a typical four-year credit requirement; as discussed above, many of these activities will not be taught as traditional lecture courses, but rather will be integrated into more active learning experiences.

Each program should design its own curriculum, but a defining characteristic will be substantial breadth and significant depth across both the sciences (natural and social) and the humanities. Following is one possible outline of curricular content, much of which will be delivered in non-traditional formats:
Math, science, engineering fundamentals: 1.5 years, with less emphasis on calculus and more on areas such as statistics, probability, linear algebra, and discrete math. A move away from solving small, “canned” problems to understanding concepts and their application is also needed. Design as a fundamental process will emerge as basic engineering preparation.

Humanities and social sciences: 1 year, preferably integrated with the engineering and science fundamentals in society-technology projects, humanistic studies of science, and/or language, area studies, and study abroad experiences.

Computer and information science and electrical and computer engineering: 1.5 years, including a substantive capstone design project. Although study of lower-level phenomena will remain important, circuit analysis will largely be replaced by system-level analysis.

Objectives and Outcomes

Following is a proposed set of Educational Objectives for the BS-level program in electrical and computer engineering: Graduates will be prepared for professional-level study in the disciplines of electrical and computer engineering as well as in the other professions, including law, medicine, and business. This education prepares students broadly for their professional and personal lives, providing the basis for informed citizenship, ultimate professional success, and formal and informal continued education.

Following is a suggestion for Program Outcomes for the BS-level program, analogous to the current eleven ABET outcomes:

1. The broad education appropriate for advanced study in engineering or other professional disciplines, including knowledge of humanities and social sciences
2. Skills in oral (both speaking and listening) and written (both writing and reading) communication

3. Understanding of the principles of computer science and of the representation and processing of information

4. Understanding of the process of design in general, and engineering design in particular

5. Understanding of, and the ability to apply in engineering design, the basic principles of an engineering discipline

6. Understanding of, and the ability to apply in engineering design, the principles of mathematics and physical and biological science.

7. Knowledge, reasoning, and analytical skills for success in graduate study

8. Understanding of the meaning and importance of professionalism, and of personal and professional ethics.

**The Professional MS Programs**

Since the MS degree would become the point of specialization, it should take many forms. For those seeking careers starting with engineering practice, MS programs focusing in various subdisciplines of ECE, with emphasis on the current state-of-the-art technology and on professional practice, will be appropriate. Traditional research-based programs focusing on analysis will continue to be suitable for those destined for PhD programs or research and development careers. Currently existing programs in management of technology, science/technology/society studies, law, and medicine will also be possible professional preparation for graduates of the pre-professional ECE degree, given its breadth and strong foundations in liberal learning.
The professional engineering MS program will require somewhat more credit hours than is typical at present, but will still be possible to complete in one calendar year fulltime, or two years halftime. Even at 36 credit hours, the amount of depth in some technical areas will be limited, and it is expected that graduate certificate programs (4 or 5 courses post-MS) will continue to grow in popularity for the great depth and focus that they can bring to a specialty.

**Getting from Here to There**

The question remains of how to get from the present situation to the proposed new environment. Who will be the advocates for the two-step approach to professional engineering? The current situation reflects self-interests of all major stakeholders. Students have been able to enter the engineering work force after only four years of college; corporations have had a large pool of potential employees among BS graduates, with lower pay expectations than at the MS level; engineering colleges have attracted students with the expectations of a good job after only four years of study. However, one can argue that the profession is now short-changed by this approach, and that ultimately each stakeholder could benefit with a perhaps somewhat smaller profession, but with more highly educated, and hence more proficient, practitioners.

A coalition of professional societies and higher education seems most appropriate to champion this change. One approach to stimulate change is via accreditation, with the elimination of accreditation of BS-level engineering programs. How could such a dramatic move be justified? The primary purpose of accreditation is to insure minimal professional competence, a difficult criterion to quantify. One could argue that if this criterion was satisfied 30 years ago when the engineering disciplines
were much less broad and deep, and when curricula included substantially more credit
hours than at present, there is reason to question how the same level of professional
competence in today’s complex technical environment could possibly be assured within
the same BS-level education.

It is certainly true that the graduates of BS-level programs can contribute to
engineering work, and it is proposed that the Engineering Technology degree continue
to be accredited at the BS level. This will certify those graduates in an engineering
support role, but accreditation of Electrical and Computer Engineering degrees should
move to the MS level. Of course, another route to implementation of this change could
be via changes in professional engineering registration requirements. However, in the
ECE profession registration is so rare that this would not impact a significant number of
graduates.

Conclusion

The changes proposed here cannot be implemented overnight, and for a
substantial period both BS-educated and MS-educated engineers will practice
professionally. However, the pre-professional degree is the logical resultant of the
forces on undergraduate ECE education, and it can address the challenges of preparing
students for leadership and success, not just survival, in a future in which the only
constant will be change. A broad undergraduate education with clear connections to
the social and global contexts of the profession will have greater appeal to prospective
students, and will prepare them for a wide array of professions both in and beyond the
engineering world. To ensure that the leaders of tomorrow can responsibly and
responsively use technology to better the world, the engineering education community must recognize engineering for the complex, professional human endeavor that it is.

Bibliography


