ELECTRICAL ENGINEERING CURRICULA

Prior to the 1880s, courses began to appear in the area of electrical engineering, initially taught in the physics or the mechanical engineering department (1). These early offerings fell far short of a course of study or curriculum. However, in 1882 a program in electrical engineering was started in the physics department of the Massachusetts Institute of Technology. In the same year many European universities began to offer a variety of courses in circuits and machinery. The first separate and dedicated department of electrical engineering was formed at Cornell in 1883. Over the next two decades there was rapid growth in both numbers of electrical engineering departments as well as the number and variety of courses taught.

As the number of departments giving degrees in electrical engineering increased, the need for a curriculum, or a canon, grew at an even faster rate. Engineering education at that time was a quasi-apprenticeship, with the student working in close proximity to the professor in order to learn the "art of engineering." The professor, in turn, was closely tied to industry, frequently getting problems as well as experience from neighboring companies. Thus the early courses offered in the nascent departments paralleled the topics of interest to the professors and industry. Between 1884 and 1889 the vast majority of technical papers published in the *AIEE Transactions* (2) were in the areas of machinery, lighting, instruments, and circuit devices. By the early 1900s the number of papers and the intensity of the work in machinery was an order of magnitude greater than the next areas (lighting and instruments).

The curricula in the early 1900s reflected the needs of industry with courses in electric power generation, transmission, and distribution, electrical measuring instruments, machinery, and an intensive laboratory for experimentation. From the catalog of Drexel Institute (the predecessor to Drexel University), in 1903 one finds that for the first two years of their education, students received training in algebra, basic English, social studies, geography, etc. In the third year, students took: calculus, chemistry—qualitative analysis, physics, mechanics of materials, principles of mechanism [sic], electricity—general theory mechanical engineering laboratory, electrical engineering laboratory, and noncredit courses in English and engineering seminary [sic]. The total number of scheduled class hours per week was 30, composed of 15 classroom hours and 15 laboratory hours. The student yearbooks from that time indicate that in fact students spent much more than 15 hours in the laboratory. In the fourth year, students would get courses and laboratories in machinery, telephone systems, dynamo design, instrumentation, machinery, thermodynamics and the steam engine, electrochemistry, building construction, telegraphs and signal systems, and noncredit courses in business, English, engineering seminary, and monthly visits of inspection. Again, students spent 30 hours per week at school divided equally between laboratory and classroom work.

In 1914, on the eve of World War I, the curriculum for electrical engineering students had begun to look surprisingly similar to that in the 1960s with the exception of the tuition,

J. Webster (ed.), *Wiley Encyclopedia of Electrical and Electronics Engineering*.

which was $70 per year at a private school like Drexel. Students still spent 30 hours per week at school; however, now more time was spent in class and less time in laboratories. Senior year consisted of 18 hours per week in subjects like dynamo design, ac circuits, telegraphy, and another four hours in civil engineering—hydraulics and structures. Economics and English are now given course credit, and the English course is on writing contracts and specifications.

In 1929 the curriculum began to become more streamlined. Total hours per week at the university ranged from 25 to 28, and some of those hours were in required military training. Required courses in public speaking, poetry and prose, and composition and literature are standard. New courses include separate courses in synchronous and induction machinery, but steam turbines remains part of the electrical engineering requirements.

In 1941, on the eve of World War II, one can scarcely find a change in the curriculum from 12 years earlier. There is one course on the theory of vacuum tubes and a new course on the differential equations of the electric circuit. Otherwise, electrical engineers went through the same curriculum as their predecessors did 10 to 20 years earlier.

World War II was a watershed for electrical engineering education in a number of ways. I heard a speech by Vannevar Bush, who had been the science advisor to President Harry Truman and who was deeply involved in the war effort, in which he said that electrical engineers were unprepared for the rapid pace of change and new technologies that arose during the intense period of the war. Looking back, through a prism forged in the 1990s, the pace of electrical engineering from its birth in the 1880s to the start of World War II in 1941 appears to be glacial. Of course to the people alive during that period, the pace was frenetic—electric lights, telephones, household appliances, traction motors, bright signs, and neon lights. However, it was the physicist and the mathematician that enabled us to develop radar and automatic fire-control systems. Major efforts such as the Manhattan Project to develop the atomic bomb and the jet engine work at Cal Tech's Jet Propulsion Laboratory required sophisticated instruments that had never been seen before. And the many efforts in automatic computation required a new look at how to solve problems. Those colleges and universities that had been heavily involved in the war effort were able to seamlessly transform their curriculum in the postwar period to include the new subjects such as electronic circuit design, microwaves, modern physics, advanced calculus which had proved so valuable to the Department of War. The newly formed Department of Defense rewarded these universities with substantial (at least at that time) research grants to continue work in these important new areas, thus positioning those schools to advance the technology and bring it into the classroom sooner. By contrast, schools that were not so involved found themselves with a now antiquated faculty and an old-fashioned curriculum. The problems in the immediate postwar period were compounded by a surge of new technical developments ranging from the transistor in 1947, the first stored-program digital computer, ENIAC, in 1948, and the beginnings of the information revolution with the publication of *The Mathematical Theory of Communications* by Claude Shannon and Warren Weaver in 1948. Coupled with the war technologies such as radar, servomechanisms, and new materials, the old curriculum for electrical engineers was, simply stated, inadequate. Yet, at a number of institutions, there were an insufficient number of "modern" faculty members to make the necessary changes.

Looking at the catalog of the Drexel Institute of Technology in 1951, six years after the end of the war, one finds, in addition to the courses that have been in the catalog for 40 to 50 years, some new courses in electronic industrial control, servo-mechanisms, radio communications, and ultra-high-frequency circuits. By 1961 there were courses in electronics (I am told by those who taught the courses that there was no mention of solid-state devices), introductory atomic physics, electromagnetic fields, and radio electronics. At this time there were graduate courses in circuit synthesis and switching theory, the forerunner to digital design.

In 1946, prompted by their perception of the inadequacy of the educational programs for electrical engineers, Vannevar Bush and Gordon Brown, the latter head of the electrical engineering department at MIT, began a major effort to revamp the curriculum for EEs by the addition of engineering science courses, basic science courses, particularly advanced calculus, and modern physics and by deleting many of the "practical" courses that had been in the curriculum for 40 to 50 years. It was rumored that the intention was to give EEs as much physics as the physics major and as much calculus as the mathematics majors. Much of the material taught to undergraduates was distilled from research and graduate programs and trickled down to the undergraduate courses. Many schools adopted this curricular model—current advanced research work is brought immediately into graduate courses and then introduced into undergraduate courses. Textbooks that flowed from MIT and other schools that adopted this model began to look less like the pre-war handbooks and more like research papers organized like monographs. These books provided the means for every school, with or without their own research program, to have current topics in the curriculum.

In 1958 MIT received a large grant from the Ford Foundation to "modernize" electrical engineering education. The immediate effect was to put a "t" after every course number indicating a transition course, as in 6.01t Introduction to Circuit Theory. Another part of the grant was used to upgrade the laboratories and to provide each student with a take-home kit of electronic components so that circuits and devices could be designed and built outside the laboratory. There were new courses introduced such as fields, forces, and motion that replaced the traditional machinery course and molecular engineering which was a wholly new course. Even in the basic circuits courses, new concepts, previously taught only to graduate students, were introduced to the undergraduates at the sophomore level. Convolution, La Place transforms, and two-dimensional signal processing put the second-year students ahead of the fourth-year students in many ways. As textbooks began to emerge from this ambitious effort, the new way of teaching percolated throughout the electrical engineering education enterprise.

In 1932, the seven major technical societies, including the American Institute of Electrical Engineers, formed the Engineers Council for Professional Development (ECPD) for the purpose of developing criteria for accrediting undergraduate engineering programs. In 1936, ECPD implemented a method of visiting engineering schools and awarding accreditation to programs that meet the minima criteria set by the sponsoring societies. ECPD became the Accreditation Board for Engineering and Technology (ABET).

In the 1960s and 1970s the continuing evolution of the digital computer prompted many electrical engineering departments to change the department name by including "computer" in some form (most commonly as electrical and computer engineering) and to add courses in digital electronics, switching theory, computer languages, and operating systems. As the number of computer courses proliferated, many of the computer-intensive departments split into separate departments of electrical engineering and computer engineering (or computer science). With the split, and the identification of computers as a separate discipline, a new computer curriculum has evolved. A new professional accreditation board emerged, Computer Science Accreditation Board (CSAB), as a parallel to ABET. The curriculum for computer-oriented programs is discussed elsewhere.

For 30 years the research/science curricular model described above persisted in nearly every engineering school in the country. By the mid-1980s, however, some engineering educators and industrialists began questioning whether the engineering curriculum was appropriate for the new workplace. Until the 1980s the workplace for electrical engineers consisted of a number of very large electronics firms that employed thousands of engineers. These engineers were almost entirely white, male, and, in this country, American. There were of course many electronics companies outside the borders of the United States, but there was little interaction among them nor was there any substantial interactions between the companies outside the United States and inside. The fact that for the entire postwar period, these electronics companies were heavily involved in defense work accounted for this separation. A typical electrical engineering graduate would begin work as a junior engineer under the supervision of a project engineer and would be working in, what is now seen to be, a homogeneous environment. Work was for a lifetime with most engineers changing jobs only once or twice throughout their careers. These large companies had marketing departments that got business for the company and was responsible for the proposals. These companies also had extensive research and development capabilities, which meant that the typical bench engineer did not have to deal with customers nor deal with the demands of new technology. The curriculum and the education of electrical engineers reinforced this paradigm, and it was that fact that started the questioning about the relevance of the engineering curriculum. The workplace was changing and the curriculum had to change with it, they felt.

In the mid-1990s, a trend became apparent that more graduates were going to work for small, start-up companies than for the established large companies. The downsizing and layoffs of the early 1990s served to accelerate this trend in the latter part of the decade. In working for the small companies, engineers find themselves involved with business, marketing, personnel problems, aesthetics, maintenance, etc., in addition to the new range of engineering challenges. Thus the curriculum had to change to accommodate the new demands of the workplace. Furthermore, many university administrators were clamoring for a reduction in required hours of instruction, catching the curriculum in a four-way bind: industry is demanding more and different skills from the graduates; administrators want time in class reduced; many universities have immutable core requirements; and ABET maintained a large number of required courses and areas of study. Something or many things had to give. The first breakout was the new curriculum initiatives, discussed later, which made the curriculum more efficient. Then ABET implemented Engineering Criteria 2000 (EC 2000), which focused on outcomes assessment and continuous quality improvement from feedback from the assessment process to inform the accreditation process. This was a major departure from what some had called a "bean counting" approach to accreditation, forcing a sea change in the way schools go about the business of establishing a curriculum.

The National Action Agenda for Engineering Education (3) called for a radical change in the way engineers were taught. Some of the issues were:

- improving the content of undergraduate programs
- role of manufacturing
- career-long development of the engineer

In response to this call for action, the National Science Foundation issued a call for proposals that would address the following areas: the overburdened curriculum, design and manufacturing, practice-oriented graduate programs, faculty development, laboratories, career-long learning, and pre-college education. The NSF received 197 proposals to reform engineering education, and they funded a large number of these. Many of the 197 proposals represented ideas that were formed into the engineering coalitions funded by NSF over the next several years. By 1989 there was a revolution started in the curriculum for engineering that was unparalleled in the previous 100 years of engineering education.

The new curricula that have emerged from these NSF-funded projects have the following features in common (4). Students have more choice in the courses they will take; nontechnical content of the curriculum has been increased; students will do more computer modeling and less paper-and-pencil computation; communication skills are developed and enhanced; teamwork is facilitated; understanding of diversity, social issues, economics, and aesthetics are all encouraged. The new accreditation criteria for engineering programs, ABET 2000, stresses outcomes assessment and self-evaluation both of which resonate with the enhanced skills that the modern curriculum offers.

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Bruce A. Eisenstein
Drexel University