COMPUTER ENGINEERING EDUCATION

Just like the area of computers, the area of computer engineering education is a fast changing field. This discussion will limit itself to the development of accredited undergraduate computer engineering education programs in the United States, and their relation to accredited programs in electrical engineering and computer science. Fortunately, because the United States has been a recognized leader in the development of computers, this narrow discussion on computer engineering education will address most of the issues regarding computer engineering education in the global context. This approach is not taken to deprecate the contributions to computer engineering education outside the United States but rather to allow this discussion to succinctly identify and address the issues that are intrinsic to all computer engineering education programs. Furthermore, since accredited undergraduate computer engineering programs now are the principal source for providing engineers who work in the discipline of computer engineering, this discussion will not address graduate education in the area of computer engineering. It is sufficient to state that graduate education in either computer science or electrical engineering will accommodate all the areas of further study in computer engineering.

To understand the nature of computer engineering education, it is necessary to relate it to the education of the computer scientists and the electrical engineers. While electrical engineering education is over 100 years old, computer science education is less than 40 years old. Accredited electrical engineering programs were established in 1936 by the precursor to the current Accreditation Board of Engineering and Technology (ABET) and accredited computer science programs were established in 1986 by the Computing Sciences Accreditation Board (CSAB). Even though computer engineering education evolved out of the computer science and electrical engineering programs, initial accreditation for computer engineering programs was administered by ABET and first granted in 1971, prior to the computer science accreditation activity. With establishment of CSAB, there appeared a dual accreditation designation for a program that educated computer engineers which was named computer science and engineering; the dual accreditation required both ABET and CSAB review of the program. Thus accredited undergraduate computer engineering education is performed at universities with computer engineering, or similarly named programs, or with a computer science and engineering program. It should be noted that there are university programs leading to a degree in computer engineering, or similarly named degrees, that are not accredited; however, without reviewing the specific curriculum and other aspects of the program, it is not possible to say with certainty that it is a program that successfully prepares students for the practice of computer engineering.

EARLY DEVELOPMENT OF COMPUTER ENGINEERING EDUCATION

Computer engineering education has developed commensurately with the development of the computer. Initially the education of the people who worked as engineers in the computer field was in other disciplines, electrical engineering, mathematics, and physics, to name a few. The first electronic computers were developed at universities. John Atanasoff (1) designed and constructed a digital computer at Iowa State at the start of World War II, and J. Presper Eckert and John Mauchly designed and built their computer, the ENIAC (Electronic Numerical Integrator and Calculator) at the Moore School at the University of Pennsylvania at the end of World War II (2). Further development of the digital computer occurred at universities such as Princeton, Harvard, Cambridge, and MIT among others, in the late 1940s (3). The activities of the graduate and postgraduate students at these institutions provided the education of "computer engineers," if you assume that the ability to design and build a computer is a central component of an education of a computer engineer. Claude Shannon's M.S. thesis at MIT in 1938 (4) related the work of George Boole and the Huntington postulates to switching circuits. In the 1950s this material began to appear in undergraduate electrical engineering curricula as a technical elective course in digital logic design.

During this same era, courses in computer programming and computing theory that would evolve into the computer science curriculum were beginning to be offered in electrical engineering and mathematics programs. As the computer science curriculum developed, there occurred a bifurcation in the development of the computer science curriculum. The direction that the curriculum took depended on the disciplines the faculty that taught the curriculum came from, electrical engineering or mathematics. In addition the discipline of the faculty who taught the early computer science programs, eventually determined whether the new departments of computer science resided in the college of engineering, or in the college of letters and sciences, or, in some cases, resided as a department in each college, one being engineering oriented and the other mathematics oriented. The engineering-oriented computer science faculty, along with the computer-oriented electrical engineering faculty contributed to the development of the first computer engineering programs.

DEVELOPMENT OF ACCREDITATION ACTIVITIES

One of the first recognized model computer science curricula was published by the Association for Computing Machinery (ACM) in 1968 (5). With this event there was established a nationally recognized computer science curriculum that evolved with subsequent model curriculum versions in 1978 and 1991 (5). With the standardization of the computer science curriculum, there was a movement to accredit computer science programs. Using the model of the Accreditation Board of Engineering and Technology (ABET), the Computing Sciences Accreditation Board (CSAB) was formed and accredited the first computer science programs in 1986.

ABET granted accreditation to a program named Computer Engineering at Case Western Reserve University in 1971. Prior (and subsequent) to this event, there were a number of reports on curriculum for computer engineering education; the reader is referred to the references in the Bibliography for details. The ABET accreditation of a program called Computer Engineering preceded the computer science accreditation activities. Subsequent to this initial ABET accreditation action for programs named computer engineering, Taylor

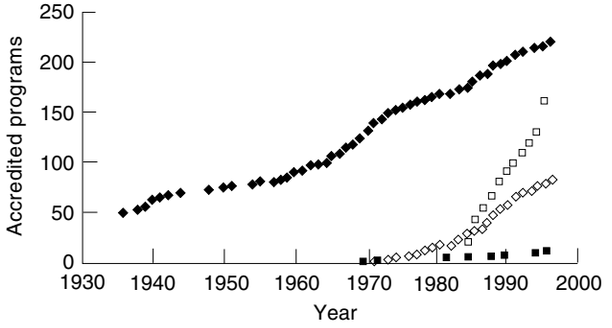

Figure 1. Accredited programs in electrical engineering (closed diamond), computer engineering (open diamond), computer science and engineering (closed square), and computer science (open square), cumulative from the initial year of their accreditation (8,9).

Booth of the University of Connecticut led an effort to define a model Computer Science and Engineering curriculum based on both the computer science and the electrical engineering curricula. This activity lead to the publication of a model program in Computer Science and Engineering in 1983 (6). This model curriculum was used by many universities to establish accredited computer engineering programs using ABET, as well as the dual accredited ABET/CSAB criteria. Currently there are two criteria that apply to every accredited computer engineering program: the ABET criteria, called computer engineering or similarly named programs, and the dual ABET/CSAB criteria for programs named computer science and engineering.

Figure 1 shows the relative growth of the four different accredited programs: electrical engineering, computer engineering, computer science and engineering, and computer science over the period of accreditation.

ORGANIZATION OF COMPUTER ENGINEERING EDUCATION

Undergraduate computer engineering education is a work in progress. The state of the curriculum for undergraduate computer engineering education is changing as fast as the field that its majors enter upon graduation. The state of the computer engineering curriculum also is affected by the administrative organization in which it resides. Most everyone will agree that foundation of the computer engineering curriculum is based on the disciplines of electrical engineering and computer science. The determination of the point of balance between the two disciplines for the foundation of the computer engineering curriculum is a matter that is determined by each university's faculty and is influenced by the organizational structure that administers the computer engineering program. There are examples of every possible organization: separate computer engineering departments within either a college of engineering or another college; computer engineering programs within departments of electrical engineering or within departments of computer science; interdisciplinary computer engineering programs between separate electrical engineering and computer science departments, where the two departments may be within the same college or in separate colleges; and computer engineering programs within administrative units that contain both the electrical engineering and computer science programs. The different organizational structures, of course, determine the computer engineering faculty administrative unit and hence the local implementation of the curriculum for computer engineering. In 1989 the members of the National Electrical Engineering Department Heads (NEEDHA) at their annual meeting held in San Diego, California, discussed the issue of the administrative structure of computer engineering programs. Their conclusion was that all logical structures are possible and that there was no recommended structure. Each university had to determine a structure to fit local needs (7). That conclusion appears to hold true in the late 1990s.

BASIC COMPUTER ENGINEERING CURRICULUM

All of the accredited computer engineering programs require four years of university education and include at least one year of basic mathematics and science, a year and one-half of engineering and computer science topics, and one-half year of social science and humanities courses. This leaves one year open for university faculty to specify other courses. For the dual accredited programs, there are additional computer science courses required. The year of mathematics and science usually contains science courses in chemistry, physics, and biology and mathematics courses in calculus through differential equations, discrete mathematics, and statistics. The engineering and computer science courses are usually balanced between electrical engineering and computer science offerings. Typically the computer engineering major will be required to take at least the same lower division courses as do each of the computer science and electrical engineering majors, and then a number of their required upper division courses. In addition there are usually a number of specialized courses that address the software/hardware interface, computer architecture, computer networks, and embedded microprocessor system design as well as advanced courses in computer science such as computer graphics and artificial intelligence, and in electrical engineering such as VLSI design and system theory.

Table 1 shows a typical accredited computer engineering program for reference. Also presented in the Table 1 data is a summary of the approximate units in each of the accreditation categories yielding a total number of 128 units. The term used for this presentation is the 15 week semester, which generally has a one-hour lecture for each unit and three-hour laboratory for each unit. It should be emphasized that while this display is typical, there are many ways to satisfy the criteria for an accredited computer engineering program that deviate from this display.

FUTURE TRENDS

At the undergraduate level there are defined criteria for undergraduate computer engineering programs. However, in the proposed ABET Criteria 2000 to be instituted in the year 2000, the program criteria for electrical engineering and computer engineering have been merged into one program criteria. Thus, except for the name of the organizational unit in which the computer engineering program resides, there could be little distinction between the electrical engineering and the computer engineering programs. If this proposal is ratified, then after the year 2000 the only distinct accrediting criteria for computer engineering programs may be the dual ABET/CSAB accreditation criteria for programs named computer

Table 1. Typical Accredited Computer Engineering Curriculum

First Year	
Term 1	Term 2
Computer Science I(cs)	Computer Science II(cs)
Discrete Mathematics(ms)	Calculus I(ms)
Chemistry(ms)	Biology(ms)
English Communication I(o)	English Communications II(o)
Digital Logic(cpe,ee)	
Second Year	
Term 1	Term 2
Data Structures(cs)	Software Engineering(cs)
Circuit Analysis(ee)	Electronics(ee)
Calculus II(ms)	Differential Equations(ms)
Physics I(ms)	Physics II(ms)
Social Science and Humanities(ssh)	Social Science and Humanities(ssh)
Third Year	
Term 1	Term 2
Operating Systems(cs)	Programming Languages(cs)
Computer Architecture I(cpe,cs)	Computer Architecture II(cpe,cs)
Digital Electronics(ee)	Linear Systems Theory(ee)
Statistics(ms)	Engineering Science Elective(ee)
Social Science and Humanities(ssh)	Social Science and Humanities(ssh)
Fourth Year	
Term 1	Term 2
Microprocessor-Based System Design(cpe)	Senior Project(cpe)
Computer Networks(cpe,cs)	Engineering Profession(o)
Technical Elective(cs,ee)	Technical Elective(cp,cpe,ee)
Technical Elective(cs,ee)	Technical Elective(cs,cpe,ee)
Social Science and Humanities(ssh)	Social Science and Humanities(ssh)
Approximate Unit Distribution	
Category	Unit Total
Basic Mathematics and Science(ms)	35
Social Science and Humanities(ssh)	18
Engineering and Computer Science Topics(cs,cpe,e)	66
Other(o)	9
Total	128

science and engineering. Therefore curriculum for programs called computer engineering after the year 2000 could be the same as those called electrical engineering and, in fact, could merely be options within the electrical engineering program, or the electrical engineering curriculum could be an option within the computer engineering program.

In addition a task force of ABET and CSAB members was formed in 1995 with the charge to plan the merger of CSAB into ABET. The results of such efforts are expected to have an effect on the accreditation of computer engineering programs in the future. So the accreditation process for computer engineering is in a state of flux at this time.

Obviously computer engineering education is also in a state of flux, and will be evolving rapidly in the next few years. Given the state of computer engineering education and its program, this discussion has to be considered a snapshot in time. This material provides some background for what will follow in the next few years, but the story of computer engineering education is far from over.

BIBLIOGRAPHY

1. N. Stern, Who invented the first electronic computer?, *Annals of the History of Computing,* **2** (4): 375–376, 1980.
2. H. H. Goldstine, *The Computer: From Pascal to von Neumann,* Princeton, NJ: Princeton Univ. Press, 1972.
3. W. A. Burks, H. H. Goldstine, and J. von Neumann, Preliminary discussion of the logical design of an electronic computing instrument, Report to the US Army Ordinance Department, p. 1, in W. Aspray, A. Burks (ed.), *Papers of John von Neumann,* Cambridge, MA: MIT Press, 1987, pp. 97–146.
4. Claude E. Shannon, A symbolic analysis of relay and switching circuits, *Trans. AIEE,* **57**: 713–723, 1938.
5. *Computing Curricula 1991 Report of the ACM/IEEE-CS Joint Curriculum Task Force,* Association for Computing Machinery, Incorporated, ACM, 1515 Broadway, New York, NY 10036-5701, 1991.
6. *The Model Program Committee,* J. T. Cain, G. B. Langdon, Jr., M. R. Varanasi (co-chairs), The 1983 IEEE Computer Society Model Program in Computer Science and Engineering, New York, IEEE

Educational Activities Board, 1983 (updated a 1977 committee report).

7. Keith Carver, History of the National Electrical Engineering Department Heads Association: A comprehensive look at NEEDHA's development, June 1992, available from http://www.needha.org/history.shtml. See Fifth Annual NEEDHA meeting: San Diego (1989).
8. *1996 Annual Report for Year Ending September 30, 1996;* Computing Sciences Accreditation Board, Incorporated, Two Landmark Square, Suite #209, Stamford CT 06901. See Programs in Computing Accredited by the Computer Science Accreditaton Commission (CSAC) of the Computing Sciences Accreditation Board (CSAB) as of October 1995 and Followed by Year of Initial Accreditation and the Engineering Accreditation Commission (EAC) of the Accreditation Board for the Engineering and Technology (ABET).
9. *1996 Annual Report for the Year Ending September 30, 1996,* Accreditation Board for Engineering and Technology, Incorporated, 111 Market Place, Suite 1050, Baltimore, MD 21202, pp. 14–34, 40–41.

Reading List

Note: To learn more about the disciplines and accreditation, the following website homepages can be visited at the URL listed.

Disciplines

http://www.acm.org Association for Computing Machinery
http://www.ieee.org Institute of Electrical and Electronics Engineers
http://www.needha.org National Electrical Engineering Department Heads Association
http://computer.org IEEE Computer Society

Accreditation

http://www.csab.org/~csab Computing Sciences Accreditation Board
http://www.abet.ba.md.us Accreditation Board for Engineering and Technology

JAMES G. HARRIS
California Polytechnic State University

COMPUTER ETHICS.

See SOCIAL AND ETHICAL ASPECTS OF INFORMATION TECHNOLOGY.