ELECTRICAL ENGINEERING EDUCATION

This article provides an overview of education, engineering education, and electrical engineering education. The historical evolution of electrical engineering and electrical engineering education is briefly traced. Then recent trends in industry and education, as they impact on engineering education, are described. Objectives for higher education and engineering education are described, as are student educational needs, outcomes, and associate metrics. Various attempts at educational reform, including engineering education reform, are discussed. An overview of quality assurance through accreditation and the current and evolving trends in accreditation activities conclude the article.

A BRIEF HISTORY OF ELECTRICAL TECHNOLOGY EVOLUTION

Humans have used such natural tools as sticks and stones in order to develop simple products for many thousands of years. In the Old Stone Age, or from the beginning of civilization until about 15,000 years ago, human development was primarily dependent upon hunting and fishing using simple stick- and stone-based tools. The New Stone Age was made possible by the development of primitive practices involving animal husbandry and agriculture, and the evolution of building technologies that led to such constructions as the Egyptian pyramids and Stonehenge. The beginning of manufacturing, using baked clay and soft metals, enabled the development of trade and commerce. The New Stone Age led to the Metal Age and to the development of wind power as a substitute for human muscle power. The printing press, the steam engine, the telescope, metallurgical and mining advances, and continuing agricultural innovations led to the Industrial Revolution. The Industrial Revolution was an advance in power and control technology. Toward the latter portion of the Industrial Revolution, advances in electrical and electronics engineering led to the discovery of the computing machine and the beginning of the Information and Knowledge Revolution.

Many conventional definitions of engineering suggest that it is the application of scientific principles to the effective and efficient conversion of natural resources into products and systems for the benefit of humankind. The notion that engineering is concerned with effective and efficient use of resources for the betterment of humankind is certainly correct. There are many constraints affecting this use and engineering is much concerned with developing solutions under resource constraints. Initially, these resources were considered to be natural resources. Today they are considered to be any of the four major resources or *capital,* as unspent resources are often now called:

1. Natural resources, or natural capital
2. Human resources, or human capital
3. Financial resources, or financial capital
4. Information and knowledge resources, or information and knowledge capital

This enlarged concept of resources enables the inclusion of such important contemporary knowledge-intensive efforts as biotechnology and biomedical engineering.

Science, on the other hand, is primarily concerned with the discovery of new knowledge. There is no inherent notion of purpose in scientific discoveries, although obviously many scientific investigations are directed at knowledge that will be of use to humanity. Knowledge of the principles of the natural and mathematical sciences is very necessary, but not at all sufficient for engineering practice. Much more is needed.

In the beginning there were two divisions of engineering: (1) military engineering and (2) nonmilitary, or civil, engineering. With increasing knowledge, civil engineering became more and more specialized to static structures and mechanical engineering emerged as the field of engineering interested in dynamics. There are four primary and traditional engineering disciplines: (1) civil, (2) mechanical, (3) electrical, and (4) chemical engineering. Each of these has several more specialized branches. There are many other important engineering disciplines, such as industrial, mining, environmental, biomedical, aerospace, and systems engineering.

Electrical engineering is concerned with the practical applications of electricity. Electronics engineering is the branch of electrical engineering that is particularly concerned with use of the electromagnetic spectrum and with such electronic devices as integrated circuits. It might be possible to make a distinction between electrical and electronics engineering on the basis of the comparative magnitude of the flowing electric currents. This is hardly, if ever, done today and the term "electronics" is infrequently used to describe academic program titles, as contrasted with the more generic term: electrical engineering. If it were done, electrical engineering would be partitioned into electrical power engineering and electronics engineering. The history of electrical engineering (1) is a very interesting and inspiring one.

Much of the world has been transformed by technology, as evidenced in an excellent work by Hughes that describes the history of American invention and innovation over the century from 1870 to 1970 (2). In particular, a tremendous growth in electrical technology occurred in the last fourth of the nineteenth century. By the early 1880s, telegraph wires largely covered the United States and underwater cables connected Europe and America. Rudimentary forms of arc lights were in use in several cities and the Pearl Street Station of Thomas Edison was supplying power for the then new incandescent lighting. There were many organizations involved in the manufacture of electrical equipment. The telephone was rapidly growing in importance as a communications instrument. While this period of time could hardly be called the information age, Beniger (3) indicates that it was actually during this period that the essence of the contemporary information age began in America.

The major increase in production and use of electrical equipment that was experienced in the latter part of the nineteenth century encouraged the Franklin Institute, a private philanthropic institution, to sponsor an 1884 International Electrical Exhibition at Philadelphia. In 1884, civil engineers, mining engineers, and mechanical engi-

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neers had each formed national professional engineering societies. There was no national electrical engineering organization at that time. A "call" for an organization of electrical engineers, signed by 25 prominent engineers of the time, was placed in an 1884 issue of the then major electrical engineering journal for the purpose of initiating formal actions to accomplish this. One of the outcomes of this exhibition was the formation of the American Institute of Electrical Engineers (*AIEE*), which held its first technical sessions during the exhibition. Some papers presented there were published in the first volume of the *Transactions of the AIEE.* The first paper in these transactions concerned the "Edison Effect," a phenomenon which became one of the foundations of electronics.

In 1902, AIEE student branches were first organized at engineering schools, with the first at Lehigh University. The AIEE was very much electrical-power-oriented and those in the "radio" world often did not feel comfortable within the AIEE. To accommodate these interests, an Institute of Radio Engineers (*IRE*) was founded in 1912, and the first issue of their journal, the *Proceedings of the Institute of Radio Engineers,* was published in January 1913. Before World War II, the IRE was small compared with the AIEE and other engineering societies. The major growth of electronic communications during and just after WW II led to an IRE membership that was much larger than the older AIEE. The then new area of electronics was attracting most electrical engineering students and the majority of new jobs for electrical engineers were in electronics, rather than in electrical power.

This led to merger discussions between the AIEE and the IRE, and the Institute of Electrical and Electronics Engineers (*IEEE*) was officially founded in 1963. Initially, it was a "learned society" of electrical engineering professionals. The *Proceedings of the IEEE* was the official journal of the new institute. In 1964, the *IEEE Spectrum* became the new core publication of the IEEE and the *Proceedings* became a separate publication devoted to more technical issues, including special issues on new and emerging electrical technologies.

In 1973 the IEEE relinquished its then exclusive role as a learned society concerned only with the advancement and dissemination of knowledge. It took on the role of a professional society that was concerned with nontechnical and with technical interests. As of the late 1990s, the IEEE membership was approximately 250,000, not including student and affiliate members, and it is now the world's largest professional society. In July 2006, the IEEE has more than 365,000 members, including 68,000 students, in over 150 countries. There are 311 sections in ten worldwide geographic regions. It is comprised of 39 professional societies and 5 technical councils representing a very wide range of electrical and electronics interests. It publishes 128 transactions, journals, and magazines. There are approximately 900 active IEEE standards and about more than 400 under current development. Thus, it can be seen that the spectrum of interests of the IEEE, and generally of electrical engineering education as well, is broad. These interests are represented by the very large number of IEEE "Professional Societies"

Aerospace and Electronic Systems Society
Antennas and Propagation Society
Broadcast Technology Society
Circuits and Systems Society
Communications Society
Components Packaging, and Manufacturing Technology Society
Computational Intelligence Society
Computer Society
Consumer Electronics Society
Control Systems Society
Dielectrics and Electrical Insulation Society
Education Society
Electromagnetic Compatibility Society
Electron Devices Society
Engineering Management Society
Engineering in Medicine and Biology Society
Geoscience & Remote Sensing Society
Industrial Electronics Society
Industry Applications Society
Information Theory Society
Intelligent Transportation Systems Society
Instrumentation and Measurement Society
Lasers & Electro-Optics Society
Magnetics Society
Microwave Theory and Techniques Society
Nuclear and Plasma Sciences Society
Oceanic Engineering Society
Power Electronics Society
Power Engineering Society
Product Safety Engineering Society
Professional Communication Society
Reliability Society
Robotics & Automation Society
Signal Processing Society
Society on Social Implications of Technology
Solid-State Circuits Society
Systems, Man, and Cybernetics Society
Ultrasonics, Ferroelectrics, and Frequency Control Society
Vehicular Technology Society

The IEEE Councils include:

Council on Electronic Design Automation
Council on SuperConductivity
Nanotechnology Council
Sensors Council
Systems Council

There are a plethora of transactions and magazines published by these societies and councils.

Some of these subject areas are very basic ones in virtually all electrical engineering educational curricula, and many educational programs offer specialized study in some of the other society and council areas. For example, the subjects of electric circuit theory, field theory, communications theory, and automatic control theory are considered generally very basic and fundamental subjects and would be found in all undergraduate programs, as generally would be power. Areas such as vehicular technology are quite specialized and would not usually be found in typical undergraduate electrical engineering curricula.

The early electrical engineers had very different backgrounds: some were formally educated, often in fields very different from engineering, and others were informally educated through experiential learning. Leaders in electrical engineering soon recognized that a new kind of education for professional practice would be needed if electrical engineering was to progress as a profession. The initial electrical engineering programs were established in the early 1880s, roughly at the same time that electrical engineers began organizing themselves professionally, and their rapid growth in following decades was very beneficial, both for the profession and for the nation.

The Massachusetts Institute of Technology (MIT), then in Boston, founded the first US-based electrical engineering program in 1882, two years before the founding of the AIEE. The initial program was a program within the physics department at MIT and, partially as a result, was heavily influenced by physics. Initially, of course, there were no electrical engineering textbooks. Development of these, as well as the development of laboratories and a cadre of electrical engineering specialists, as professors and as practitioners, were among the very early and important tasks for the new profession.

Initially, the electrical engineering curriculum was comprised almost totally of electrical power engineering courses. Some of the initial electrical engineering professors distinguished themselves in innovation and research, as well as in education. Others devoted their full-time efforts to education. The great importance of radio and the many possible opportunities for utilization of vacuum tubes and telephonic communications suggested that these subjects deserved a place in the curriculum of even the most strongly electrical-power-focused electrical engineering department. The resulting "communications option" began in an effort to make electrical engineering education more responsive to changing technology and changing needs of industry and society.

These changes also led to establishment, generally in the 1920s, of "cooperative electrical engineering" programs, which allowed students to alternate periods of employment with periods of study. The first part of the twentieth century, and the significant impact that engineering and engineers had on society, found engineers in new societal roles, and this led to debates concerning the role of the engineer in society. Such issues as control of the radio spectrum were of great governmental, organizational, and societal importance, and led to establishment of the Federal Radio Commission in 1928, as a cooperative venture between radio engineers and government regulators.

The importance and role of the engineer in society has increased markedly since that time. The discovery, in 1947, of the transistor by scientists at Bell Laboratories provided the electrical engineer with the ability to exploit an entirely new electronic world that was then unknown. It was the semiconductor that was responsible for the evolution of the digital computer, even though these computers had certainly existed earlier through relay (which is where the term "computer bug," as a real physical hazard, was first used) switching circuits and vacuum tube switching circuits. Without the ubiquitous digital computer, the various space adventures of the mid twentieth century would not have been possible. However, the decline of the space program and military programs in the 1970s led to a period of unemployment for electrical engineers, approximating 6%. While not high compared with nonprofessional laborers, this was so highly unusual in the engineering profession that it led to considerable declines in engineering enrollments. It was during this period of unrest that the IEEE reformed itself as a professional, rather than only as a strictly learned, organization.

Microelectronics and integrated circuit related efforts, including digital computers and communications, became the "glamour" technologies of the 1970s and 1980s. These technologies have produced profound impacts on society and on the electrical engineering profession. The ease of development and the power of integrated circuits have actually changed the way electrical circuits are architected and then designed, and have led engineers to actively search for digital solutions to problems that are not themselves inherently digital. For example, the simulation of continuous-time dynamic physical systems, such as aircraft, is now accomplished almost totally digitally, even though the physical systems themselves are continuous-time systems for which much analog computer technology had been developed in the 1950s and 1960s. This "digital everything" trend has resulted from the major developments in semiconductors, abilities at very large scale integration of electronic circuits, the resulting microprocessor-based systems, and associated major reductions in size and cost of digital computer components and systems.

The digital revolution (4) has led to a death of distance (5), through the merging of telecommunications technology and computer technology into information technology, and the emergence of networked individuals and organizations. The major characteristics of this change include great speed (6) and the major necessity for engineering, including electrical engineering, to be especially concerned with social choice and value conflicts issues (7) that surround strategic management of the intellectual capital (8) brought about by the information technology revolution and the use of information technology for organizational and societal improvement. The initial focus on data in the early days of computers shifted to a focus on information and information technology in the decade of the 1990s. Now the imbedding of information concerns into greater concerns, which affect knowledge resources and the need for transdisciplinary issues of knowledge integration, must be addressed well in order to ably handle the concerns of the early twenty-first century. This is bringing about major changes (9) and needs for engineering education to adapt programs to these changes such that the customers of engineering education—students and employers—remain satisfied with educational product quality.

In the early days of human civilization, development was made possible through the use of human effort, or *labor,* primarily. Human ability to use natural resources led to the ability to develop based not only on *labor,* but also on the availability of *land,* which was the classic economic term that implied natural physical resources. At that time, most organizations were composed of small proprietorships. The availability of financial *capital* during the industrial revolution led to this as a third fundamental economic resource, and also to the development of large corporations and resulting steep hierarchies. This second wave is generally associated with centralization, mass production, and standardization. Major availability of information and knowledge has led to *information* and associated *knowledge* as a fourth fundamental economic resource for development. This is the era of total quality management, mass customization of products and services, of reengineering at the level of product, process, and systems management, decentralization and horizontalization of organizations, and integration at the level of products, processes, and organization. While information technology, a product of electrical engineering effort, has enabled these changes, much more than just information technology is needed to bring them about satisfactorily.

The transition from the mainframe and minicomputers of the mid-twentieth century to client server computing and networking of the very late twentieth century, and the associated changes in organizations and society, have not come without concerns for growth and progress. During the decade of the 1980s and early 1990s, many asked what has happened in the past quarter century relative to this continued progress. Concerns were expressed in the 1980s and early 1990s on the subject of declining US innovation and productivity. Generally, the papers and books of that period furnished suggestions to enhance technological and management efforts in such a way that would lead to renewed efforts to enhance competitiveness through innovative research and development, associated technology transfer, and better use of human resources. Some of these writings suggested that America was in potentially deep trouble, being devalued (10) through a perceived unmaking, or "dumbing-down," of education and associated declines in many social and political institutions. Illiberal education (11) was claimed to result from "politically correct" expediencies that were felt to be rapidly eroding the long-standing traditional mores of scholarship and individual distinction throughout much of American higher education. These have purportedly been replaced with a dogmatic, intolerant, and repressive new-liberalism (12). This is nourished by rapid increases in entitlements to individuals and groups, but with fewer and inadequate resources available to assure their availability. The net result was perceived to be a decline on virtually all fronts.

ProfScam (13), in which many American university professors arrange teaching schedules, often through substitution of full course teaching efforts with very modest sponsored research charges, such that low-paid and often marginally qualified surrogates in the form of teaching assistants and adjunct faculty cope with a large part of the student credit-hour production in the classroom, was cited as a contemporary reality. This allows professors to engage in more highly preferred and self-indulgent activities that are generally funded by the inadequately serviced student credit-hour earnings of the university. This is claimed to result in high cost and low quality for much of American higher education. These inferior solutions in higher education were claimed to contribute to many related difficulties concerning American productivity and innovation, primarily through a failure to provide the emphasis on human resources needed for a competitive America.

Elementary and secondary education have not escaped similar criticisms. A 1983 report espoused the view that any external imposition of the situation then extant in education would likely have been proclaimed as "an act of war" (14). The report goes on to describe what is called acts of "unthinking, unilateral educational disarmament." In the minds of many, the situation had deteriorated and the American educational system deserved "failing grades" (15) on a variety of important performance facets.

Schlesinger (16) claimed that a disuniting of America has resulted from a shift in the traditional concept of America as a melting pot of individuals from all nations who join together and seek new lives. This has been replaced by an ethnicity upsurge in which America is viewed as distinct diverse groups with indelible cultural characteristics. While healthy consequences have resulted from this, such as overdue recognition of equality of opportunity across race and gender, it is also claimed to have resulted in a sacrifice in traditional American beliefs in individual responsibilities and subordination of these responsibilities to notions of group rights and entitlements. Indeed, warrants and backings have been provided (17) to support the claim that contemporary programs to ensure rights and entitlements at the expense of responsibilities have been genuinely counterproductive to the progress of the very individuals whose rights are presumably protected, but whose opportunities for emergence from their present state are thereby ultimately and significantly degraded.

Related inquiries have focused more on technology, economic, and managerial issues supporting innovation and productivity. It was argued that the laws, regulations, and practices that are associated with corporate management and governance, investment practices, and executive compensation all favor a short-term, myopic perspective. This focus on "short term America" (18) was said to occur at the expense of the long-term view, leading to disinterest in developing the technologies and manufacturing the products and systems that will ensure increasing market share and the associated long-term accomplishments and subsequent and affiliated affluence of a productive America.

Various contemporary investigations have suggested improvement strategies, such as for reinventing the factory (19) in order to enhance US participation in the ongoing quest for world markets. Competitiveness through increased advancement of emerging information technologies was a major thrust of many of these works.

It was argued strongly (20), that information technology studies and developments extend much beyond the neoclassic engineering of data processing to incorporate intellectual property laws, public- and private-sector policy considerations, and economic and systems management considerations. Four major strategies were suggested in this effort:

1. Redefining the technology base to include information as an essential ingredient
2. Leading in the development and application, often through technology transfer, of new and emerging technologies
3. Capturing market share and dominating the commercial production sector
4. Controlling the use of information technology in national security applications.

The major substance of this, and other works, was that there are indeed strategies that can restore what once did exist concerning productivity and quality and that properly managed information technology could represent a major supporter of these developments.

In the late 1980s and early 1990s, there was an abundance of studies associated with strategies to regain the productive edge, such as an excellent MIT Commission on Industrial Productivity study (21), which identified four then existing adverse facets that detracted from American productivity in a changing world economy:

1. *Technological weaknesses in development and production,* especially in terms of design for manufacturability and quality
2. *Neglect of human resources* in terms of formal education and training, and neglect also of on-the-job reeducation and retraining
3. *Failures of cooperation* within individual organizations, in an interorganizational sense, and with respect to labor–management relations
4. *Government and industry at cross-purposes,* especially with respect to regulatory policies, technological infrastructure issues, and the lack of technology-transfer mechanisms to capture as many direct and indirect benefits of military research and development

This discerning work suggested a number of strategies for industry, labor, government, and education that would potentially lead to a more productive America. The four identified critical success factors for students and faculty are of particular interest here. Stated as objectives, these were:

1. To encourage strong interest in and knowledge of real problems from economic, social, and political perspectives
2. To encourage team efforts in the creation of new processes, systems, and products
3. To develop the ability to function effectively beyond the confines of a single discipline
4. To develop the ability to integrate a deep understanding of science and technology with practical knowledge, including the necessary human and experimental skills and insights

A major objective espoused in studies of this sort was increased recognition of the critical issues and interactions associated with university education and national productivity. Contemporary efforts at revitalization of engineering education are based in large part on such studies as this.

There were such other studies as a 1991 report from the National Research Council (22), which identified five major categories of national need:

1. *Systems management for technology development,* including management of product-development processes throughout the entire systems life cycle
2. *Management of complex large-scale processes,* such as highly automated flexible manufacturing or broad band telecommunication systems that necessarily have much different management requirements from those of management of low-technology enterprises
3. *Using technology for competitive advantage,* in particular, including the use of such modern information technology developments as management information systems and decision-support systems that offer major potential for successful integration of technology-management and enterprise-management strategy
4. *Technology–organization interactions,* including concerns of successfully integrating technology into the organization, and having technological solutions accepted by those charged with using them
5. *Social impacts of technology,* including developing technologies that are societally acceptable and environmentally acceptable

Studies such as these have led to major reengineering efforts across industry and, perhaps to a potentially lesser extent, government. Such efforts as total quality management, reengineering, strategic sizing, organizational learning, and associated information technology and knowledge-management efforts have led to major improvements in systems-management capabilities. To a great extent, systems engineering and information technology (23), now much associated with knowledge management (24) and knowledge sharing (48), as enabled by information technology, have been the catalysts for these changes.

While the changes in the industrial and government sectors occurring over the last decade and a half have been remarkable and have led to the US regaining the competitive edge (25), changes in the university are generally judged to be less appreciable and less effectual, and suggestions for change continue to abound.

For example, in 1996 Anderson (26) suggested ten critical points for university revitalization:

1. *Prohibit student teaching* by the thousand of graduate students, generally pursuing doctoral degrees, who routinely teach undergraduates.
2. *Cease rewarding spurious research.*

3. *Change the nature of doctoral programs* such that they emphasize other than *research.*
4. *End faculty tenure* in favor of a performance-based system.
5. *Reorganize faculty titles and responsibilities* such as to distinguish primarily teaching efforts from those involving mostly research and publication, for whom the title of Fellow might be more appropriate.
6. *Return to the four-year undergraduate degree,* as contrasted with the approximate five-year degree which has become the norm in many institutions.
7. *Take sexual harassment seriously.*
8. *Ban political discrimination.*
9. *Stop athletic corruption.*
10. *Crack down on institutional corruption.*

These were suggested as strategies and action items that could do much to restore the university as a place of teaching and learning. That a decade has elapsed and many still consider them challenges speaks to a major need.

Donald Kennedy, president emeritus and professor at Stanford University, wrote in 1997 about contemporary university issues and suggests that meaningful reform will not occur until more rigorous standards of responsibility are accepted by administrators and by faculty. He suggested eight major areas for reform, stated in the form of objectives (27):

1. *To teach,* as the core responsibility of a university whose major products are educated people
2. *To mentor advanced students* in a one-on-one interactive and ethical manor such as to best develop inquisitive minds
3. *To serve the university* through active participation in governance and outreach efforts
4. *To discover new knowledge* through research in a manner that deals both with sponsors of research as well as with questions of authorship and credit in a responsible and ethical manner
5. *To publish* in a manner appropriate for the academic area of the scholar and to provide appropriate and proportional credit to the authors of the work in question
6. *To tell the truth* and avoid all forms of impropriety and misconduct
7. *To reach beyond the walls* of the institution to accomplish technology-transfer and other service efforts while avoiding conflicts of interests
8. *To change* in such a manner as to reengineer the university and its faculty to make education continually meaningful, to make appropriate use of new technologies for instruction, and to ensure quality management of the educational enterprise

While each of these were here addressed to the university in a general context, they have obvious applicability to engineering programs, including electrical engineering programs.

In an insightful article (28), it was noted that a 1994 National Education Goals Report indicated that fewer than half of adults in the US have the literacy skills to compete successfully in the global economy or to exercise the rights and responsibilities of citizenship. The question raised was how can the United States have the finest college-level education system in the world and at the same time have a K–12 (kindergarten through twelfth grade) system that is often mediocre or worse? Three major Improvements were suggested:

1. The needed improvements are comprehensive ones that address all parts of the education system, from public policies to classroom practices.
2. The hoped-for improvement must start with the development of challenging, rigorous standards. This should be coupled with a system of testing that provides measures of success and which also suggests the path to improvement and how students, educators, and the community can be made accountable for fulfilling these needs.
3. Organizations outside of the schools need to provide real-world incentives for students to work hard and do well in class.

Four "waves" of organizational involvement in school reform were cited:

1. Individual school partnerships, adopt-a-school programs, and similar stand-alone efforts
2. Transfer of such management principles as total quality management to schools
3. School choice and higher academic standards seen as quick-fix silver bullets
4. Abandoning ad hoc programs and addressing interrelated educational conditions, from public policies to classroom practices

It was felt that the fourth wave, the most recent, offered the maximum possibilities for true and lasting success.

Concerns have been expressed with efforts that relate to engineering education and science education as well. In a 1996 report of the National Research Council (29) it was encouraged that all students be provided with "opportunities for access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology, and that all students learn such subjects by direct experience with the methods and processes of inquiry."

The report specifically recommended that all US undergraduates attain a higher level of competence in science, mathematics, engineering, and technology. Universities were encouraged to provide these opportunities for all students, and not just for those seeking an education in engineering or science. Important recommendations were produced for faculty and for administrative units. Faculty members were encouraged to believe and affirm that every student can learn, and to emulate good practices that increase student learning. They were encouraged to have high expectations, to provide a supportive environment that encouraged inquiry, and to stress the excitement of discovery, communication, and teamwork, critical thinking, and the development of life-long learning skills. Administrative units and governing boards were encouraged to set goals and accept responsibility for undergraduate learning, to use technology to enhance learning and encourage an active learning environment, to reexamine institutional missions in terms of undergraduate needs, to develop reward systems that stress the importance of science and engineering education for all students, and to provide strong programs for faculty development and to reward faculty who demonstrably facilitate student learning. Accrediting agencies were encouraged to fuse principles of sound undergraduate education into accreditation criteria, and to focus on student learning and not just on organizational and process issues.

Comments on the changing environment for engineering and engineering education are commonplace, and issues such as the following seven are often cited (30) today, just as in 1997 when this writing was first published:

1. Availability of many new engineered materials, and an associated much larger "design space" from which the engineer must choose
2. Pervasive use of information technology in the products and process of engineering
3. Increasing number and complexity of constraints on acceptable engineering solutions—where cost and functionality were once the dominant concerns, ecological and natural resource concerns, sustainability, safety, and reliability and maintainability are now also major concerns
4. Globalization of industry and the associated shift from a nationally differentiated engineering enterprise to one that is far more global
5. Major increases in the technical depth needed in manufacturing and service sectors, both in terms of absolute specific technical knowledge and breadth of knowledge needed
6. Expanded role of the engineer as part of integrated product and process teams, and the broad business knowledge required
7. Increased pace of change in which there appears to be less time to assimilate and adapt

Each of these, individually and especially in combination, has lead to many new challenges for engineering education.

On the basis of concerns such as these, there have been many proposals for reshaping graduate education in science and engineering (31), and designing an adaptive system for engineering education (32). There have been a number of other recent studies of engineering education, in large part prompted by the challenges and needs denoted earlier. Under the auspices of the Education and Human Resources (*EHR*) Directorate of the National Science Foundation, a committee of the Advisory Committee to EHR has conducted an intensive review of the state of undergraduate education in science, mathematics, engineering, and technology (*SME&T*) in the United States (33). The purpose of this 1995 review was to consider the needs of all undergraduates and to recommend ways to improve undergraduate education in SME&T. Four of the essential conclusions of this study were as follows:

1. All students should have access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology.
2. All students should learn these subjects by direct experience with the methods and processes of inquiry.
3. All undergraduates in the United States must attain a higher level of competence in science, mathematics, engineering, and technology.
4. Students should learn not only facts concerning science, but also the methods and processes of research, what scientists and engineers do, how to make informed judgments about technical matters, and how to communicate and work in teams to solve complex problems.

These conclusions were strongly influenced by the reality that, in an increasingly technical and competitive world, with information and knowledge as a major determinant of competitive advantage, the lack of a properly educated citizenry places a society at significant risk.

In one notable and particularly relevant 1994 work (34), relevant, attractive, and connected engineering education was outlined as education that results from engineering programs that undertake several important action items, eight of which are listed below:

1. *Establish individual missions for engineering colleges,* such that an effective planning process that enacts a clear vision supportive of excellence drives each program.
2. *Reexamine faculty rewards,* such as to identify incentives that assure commitment and which support the programmatic mission.
3. *Reshape the curriculum* to enable relevance, attractiveness, and connectivity.
4. *Ensure life-long learning* of all, supported in part by new and innovative technologies for education (35).
5. *Broaden educational responsibility,* such that engineering programs provide support for elementary and secondary education.
6. *Accomplish personnel exchanges,* such that faculty are able to obtain relevant experience in industry and government, and such that industry and government experience are able to contribute their talents to programs in engineering education.
7. *Establish across the campus outreach,* such that high-quality and relevant courses in engineering are made available throughout the university.
8. *Encourage research/resource sharing, open competition based on peer review, and enhanced technology transfer.*

The attributes associated with reshaping the curriculum are of special importance, in that these are directly focused on educating students for careers as professional engineers, for research, for planning and marketing, and for the many other functions performed by engineers. The major ingredients associated with reshaping the curriculum were suggested as:

- Team skills, and collaborative, active learning
- Communication skills
- Systems perspective
- Understanding and appreciation of diversity
- Appreciation of different cultures and business practices, and understanding that engineering practice is now global
- Integration of knowledge throughout the curriculum
- Multidisciplinary perspective
- Commitment to quality, timeliness, and continuous improvement
- Undergraduate research and engineering work experience
- Understanding of social, economic, and environmental impact of engineering decisions
- Ethics

Sections of this important report are addressed to each of these important ingredients.

That attention still needs to be paid to these desiderata is emphasized in a 1998 writing by the president of the US National Academy of Engineering that discusses the still-compelling urgency of engineering reform (36) relative to such important issues as:

- The need for much more design synthesis in the curricula—under economic, quality, integration, and other constraints—as contrasted with the current focus on scientific-based analysis
- The need for focus on the rapidly increasing role of new innovations in such areas as information technology and biotechnology
- The need for all, including the "liberally" educated, to be technologically literate
- The need to seriously examine whether a realistic 120-semester-hour bachelors degree in engineering can be considered as a first professional degree

Other relevant works examine the role of technology and values in contemporary society (37). Still others stress the need for engineering to become more integrated with societal and humanistic concerns, such as to enable engineers to better cope with issues and questions of economic growth and development, and associated concerns regarding sustainability and the environment (38). These issues are continually being addressed in the international engineering education community. Two recent reports (49, 50) describe the situation facing engineering and engineering education in the year 2020. The first of these studies (49) suggests that the engineering profession should take the initiative in defining its future. However, to do this successfully, the report presents cogent arguments that the profession must

1. Come to agreement on a vision for its future;
2. Transform engineering education to help achieve this vision;
3. Establish a clear image of the resulting new roles for engineers, including becoming broad scope technology leaders and establishing this image in the perceptions of the public and prospective students;
4. Accommodate innovative developments into engineering that arise initially in non-engineering areas; and
5. Find approaches that will focus the energies of the different disciplines of engineering toward common agreed upon objectives that will ensure world sustainability and progress.

While the results of this study indicated that there is no consensus on strategies and tactics at this time, it was agreed that innovation is the key driver and that engineering is essential to enabling innovation. However, it was stressed that engineering will only be able to contribute to success if it is able to continue to adapt to emerging new trends and to educate the next generation of students by providing them with knowledge principles, practices and perspectives needed for the world as it will be tomorrow, and not as it is today.

In the second report (50), specifically on engineering education, a dedicated effort was made to answer the question, "What will or should engineering education be like today, or in the near future, to prepare the next generation of students for effective engagement in the engineering profession in 2020?" The report is very concerned with identifying approaches to enrich and broaden engineering education so that the products of the educational process will be better prepared to work in today's constantly changing economy. The report does discuss education after the baccalaureate degree; however, its major focus is on undergraduate education, and not graduate level education or academic research. There were fourteen major recommendations of this study relative to reengineering engineering education.

1. The baccalaureate degree should be recognized as the "pre-engineering" degree or "bachelor of arts" in engineering degree.
2. Engineering schools should create accredited "professional" masters degree programs intended to expand and improve the skills and enhance the ability of engineers to practice engineering. In support of this, the Accreditation Board for Engineering and Technology (ABET) should change their present policy and allow accreditation of engineering programs of the same name at both the baccalaureate and graduate levels in the same department.
3. Engineering schools should exploit flexibilities inherent in the outcomes-based accreditation approach of ABET to experiment with novel models for engineering education. ABET should ensure that evaluators look for innovation and experimentation in curricula and not hold to a strict interpretation of the present guidelines as perceived by individual eval-

uators. In this way, each college and university is allowed and encouraged to develop their own plans and programs that best suit their stakeholders and then be evaluated on whether the plans are efficacious and whether the desired outcomes of this planning are achieved.

4. The iterative process of designing, predicting performance, building and testing–should be taught from the earliest stages of the curriculum, including the first year. This supports the emergent, evolutionary, and adaptive nature of an engineering education system of systems, as noted earlier. It also encourages a broad interpretation of these iterative process activities to include early attention to associated educational benefits analysis and assessment.
5. The engineering education establishment, potentially through the Engineering Deans Council, should endorse research in engineering education as a valued activity for engineering faculty.
6. Colleges and universities should develop new faculty qualification standards such as, for example, to require experience as a practicing engineer. They should adapt their faculty development programs to support professional growth of engineering faculty.
7. Engineering schools must teach engineering students how to learn, and work along with professional organizations in facilitating life long learning.
8. Engineering schools should introduce interdisciplinary learning in undergraduate programs, rather than only having it as a possible feature of graduate programs.
9. Engineering educators should explore the development and use of case studies of engineering successes and failures and should encourage appropriate use of case studies in undergraduate and graduate curricula. In this connection, we note current INCOSE efforts to develop systems engineering case studies.
10. Four-year engineering schools should work with local community colleges to assure effective articulation, in as seamless as possible a manner, with 2-year community college programs.
11. Graduate students from all over the world have flocked to the U.S. for years to take advantage of the excellent graduate education available. At the same time, they should not to neglect domestic students. Thus, U.S. engineering schools must develop programs to encourage/reward domestic engineering students to aspire to the MS and/or Ph.D. degree.
12. Engineering schools should support national efforts at improving math, science and engineering education at the K-12 level.
13. The engineering education profession should participate in coordinated national efforts to promote public understanding of engineering through public technology literacy.
14. The National Science Foundation (NSF) should collect comprehensive data concerning engineering department/school program philosophy and student outcomes, such as student retention rates by gender and ethnicity, percent of entering freshman that graduate, time to degree, and information on jobs and admission to graduate school. The purpose of this would be to provide marketplace information, knowledge, and understanding across programs.

While this particular report is devoted in large part to USA based engineering education, analogous statements can generally be made relative to international engineering education, including education in electrical engineering.

OBJECTIVES FOR HIGHER EDUCATION AND ENGINEERING EDUCATION

Engineering education is a professional activity and an intellectual activity. It is necessary that the faculty responsible for this educational delivery in engineering remain at the cutting edge of relevant technologies, including emerging technologies, as technology does change rapidly over time. Research is, therefore, an absolute essential in engineering education. It is possible through relevant research, and associated knowledge principles, to develop new engineering knowledge principles and practices that are relevant to societal improvements that result from better use of information and technological innovations. Research is exceptionally important for engineering education, as it is strongly supportive of the primary educational objective of the university. It is vital to remain vigilant relative to the educational mission and, again, this requires that faculty remain at the cutting edge of technology in order that they be able to provide education, meaning *teaching and meaningful learning by students,* at that forefront. It is because of the need to remain current in the classroom in order to deliver education for professional practice that the strong need and a mandate for faculty research in engineering necessarily emerges.

This suggests that research activities in engineering education should generally be very student oriented. It suggests that students are an inseparable and integral part of faculty research. It suggests a major role for students in development and cooperative/internship ventures with industry and government. This creates the strong need for sponsored research and internships that assure the needed industry–government–university interactions. In addition to being intimately associated with the educational process, sponsored research also provides faculty with released time from exclusively teaching efforts for and enables them to engage in scholarly pursuits necessary to retain their currency in the classroom. Also needed is the innovative effort that transfers research in emerging technologies to engineering practice with potential marketplace success. These each have a mutually enhancing and beneficial effect when properly and ethically associated with the educational function, and when this research is attuned to the needs associated with knowledge integration for professional practice.

The knowledge and skills required in engineering, and in engineering education, come from all of the sciences, and from the world of professional practice. This suggests that faculty in a professional school of engineering need to keep abreast of progress in relevant sciences, both the natural sciences and the economic and social sciences, and the mathematical and engineering sciences. Taken together, these comprise knowledge principles. It suggests also that engineering educators must keep abreast of and contribute to industrial practices in relevant professional practice areas. It is for this reason that engineering schools are and must remain *professional schools.* This is also why close *industry–university* and *government–university interactions,* become a most desirable and, in fact, essential part of successful, high-quality engineering education programs.

Efforts in engineering must necessarily involve likely future technological developments as well, if the customers for electrical engineering education are to be satisfied. Thus, there is a need for *knowledge practices, knowledge principles,* and *knowledge perspectives* in engineering education. These knowledge components, and the necessary learning to enable transition and natural evolution of one form of knowledge into the other, are very important for both technology transfer and for engineering education.

This leads to success attributes for faculty in electrical engineering education that include quality teaching, quality scholarship and sponsored research, and quality professional service. This suggests that faculty should be productive in terms of high-quality teaching, research, and professional service. Also it suggests that they should have a quality culture and orientation that indicates continued productivity and trustworthiness over time relative to performing one of societies more important functions—that of education. Thus, the five Cs—competency, commitment, communications, collaboration, and courage—are very important success attributes for faculty.

As noted in a previous section, there has been much recent concern that teaching has become a neglected ingredient in these educational performance attributes, rather than the dominant one that it should be. This is the major theme of a noteworthy work by Boyer (39), in which the author suggests four dimensions of a reconsidered and redefined scholarship. These are:

1. *The scholarship of knowledge discovery,* which is the classic form of research in one well-established and defined discipline
2. *The scholarship of knowledge integration,* which is interdisciplinary or cross-disciplinary or multidisciplinary or transdisciplinary scholarship and research that involves the blending and infusion, or transfer or integration, of knowledge across several disciplinary areas
3. *The scholarship of knowledge application,* which is the utilization of knowledge to support such worthy endeavors as policy analysis, program evaluation, and professional service
4. *The scholarship of teaching,* which involves the communication of one's knowledge to others, generally in the classroom, perhaps an extended- or distance-learning classroom.

No responsible educator could deny the importance of these four facets, nor should there be disagreement that the fourth facet listed by Boyer, the scholarship of teaching, should really be the first-priority facet for education. These four forms of scholarship are not at all dramatically different from the mix that results from consideration of the interaction of knowledge principles, practices, and perspectives across the three traditional university faculty efforts of (1) teaching, (2) research and scholarship, and (3) public and professional service. Nevertheless, the notion of each of these four as important is vital, as well as the uncommon assertion that teaching and application are each forms of appropriate scholarship for university faculty.

What Boyer denotes as scholarship of discovery appears equivalent to research and breakthroughs relative to knowledge principles. Discovery can, of course, relate to knowledge perspectives as well. Discovery can surely involve only a single established area of inquiry or, as is much more likely to be the case when knowledge perspectives about future developments are concerned, inter-, cross-, multidisciplinary efforts. Thus, research into and knowledge of integration, or the scholarship of knowledge integration, appears to be much a blend of knowledge principles and knowledge perspectives and the transition of these into knowledge practices. The scholarship of knowledge application would, in a similar way, seem quite equivalent to knowledge practices. Teaching is, of course, the primary activity involved in communicating knowledge practices, knowledge principles, and knowledge perspectives to others. It is often suggested that much academic research is too narrowly focused to truly support the educational function, which needs to be more broadly based and integrative. Doubtless this assertion is correct. What this suggests however, is not neglect of research and knowledge principles, but a renewed focus on the large-scale and broad-scope facets of integrative knowledge-based efforts. This suggests a simultaneous *broad-narrow* perspective on knowledge acquisition and management efforts, especially as they relate to engineering practice and engineering education for professional practice.

The real thrust of the Boyer message is indeed critical: *Teaching is important, even and especially including undergraduate teaching. It has been neglected in some sectors of higher education. Its importance clearly needs to be reconsidered and reestablished. The faculty reward structure must recognize, now and for all time to come, teaching as a very important ingredient in the performance of an educator.* Whether or not teaching is a form of scholarship is thus completely irrelevant to the central and much needed message in this important work.

A 1997 work, denoted as an Ernest L. Boyer project of the Carnegie Foundation for the Advancement of Teaching (40), set forth six standards that can be used to develop metrics to assess the four scholarship divisions:

1. Clear goals for scholarly work
2. Adequate preparation in terms of understanding existing scholarship and having appropriate resources to enable progress

3. Appropriate methods that have been properly adapted to enable success
4. Significant results that significantly impact the scholarship division in question
5. Effective presentation and communication of the results of the scholarly effort
6. Reflective critical personal evaluation of the work by the scholar performing it

The three essential characteristics of a scholar are represented to be (1) integrity, (2) perseverance, and (3) courage. To these, one might add competence, commitment, communications, collaboration, and much tolerance and humility.

There are a number of economic and accounting issues that need only be mentioned briefly here. There are faculty earnings necessarily associated with student credit-hour production, and charges for and earnings from sponsored program activities. These are essential as an educational enterprise must support itself. These represent the earnings of the institution from the academic enterprise. Two other important financial measures are (1) billings, or the accounts to which university personnel charge time, and (2) activities, or the productive efforts of the faculty. While generally associated directly with earnings and billings, there is not necessarily a one-to-one correspondence among these three entities: (1) earnings, (2) billings, and (3) activities. Quality educational enterprise management must necessarily be concerned with all three of these. This article will not be especially concerned with these issues, important as they are for efficient and effective operational management of the enterprise supporting engineering education.

STUDENT EDUCATIONAL NEEDS, OUTCOMES, AND METRICS–AND PROGRAM ACCREDITATION

Notions of what comprises an appropriate education are not at all new. Many have written, and for a very long time, about educational requirements and the characteristics of educated people. In 1852, for example, John Henry Cardinal Newman identified ten distinctive traits of university education (41). An interpretation of these is as follows:

1. It encourages one to identify and place values upon personally held views and judgments.
2. It encourages search for the truth.
3. It encourages eloquence in expressing truths.
4. It encourages clarity and integrity in observing and valuing judgments.
5. It encourages coherency of expression and communication.
6. It encourages one to solve problems through critical thinking skills and by analyzing courses of action, such as to be able to retain meaningful alternates and to discard spurious ones.
7. It encourages cultural and cross-cultural understanding.
8. It encourages compassion, forbearance, and comprehension of the views of others.
9. It encourages basic feelings for and understandings of events in both a social and a historical context.
10. It encourages preparation for work and a lifetime of continued learning.

These are as relevant today as they were when initially written in a somewhat different style, one-and-a-half centuries ago.

Five study areas: (1) *humanities,* (2) *social and behavioral sciences,* (3) *natural sciences,* (4) *mathematical sciences,* and (5) *engineering sciences* are absolutely essential for provision of the general education background and perspective needed for professional practice in engineering, and for development of abilities to use knowledge principles and to successfully convert them to knowledge practices as well.

Any professional educational program should, unless it is to ultimately suffer any of several impediments to its integrity and trustworthiness, become accredited by the appropriate accrediting agency. Accreditation has, for a very long time, been recognized as a mechanism for quality assessment of educational programs. It has had an especially significant history with respect to professional programs, such as engineering and computer science.

Programs that have engineering in their title are potentially subject to accreditation by the *Accreditation Board for Engineering and Technology* (*ABET*) which, prior to 1980, was called the *Engineers' Council for Professional Development* (*ECPD*). ABET is a federation of some 28 engineering professional societies and is recognized by the US Department of Education (*USDoE*) and the Council on Postsecondary Accreditation (*COPA*) as the sole agency responsible for accreditation of all educational programs leading to engineering degrees in the United States. ABET does not currently accredit programs outside of the United States unless these are at an institute that has intimate educational connections with a US university. ABET will evaluate programs outside the U.S., by institutional request, to determine if they are "substantially equivalent" to ABET-accredited programs and to make recommendations for program improvement. The initial accreditation planning for, and implementation of, computer science accreditation was accomplished through ABET, and the Institute of Electrical and Electronics Engineers (IEEE) within ABET. This became a separate but related accreditation effort, for computer science but not for computer engineering, within the *Computer Science Accreditation Commission (CSAC) and Comptter science Accreditation Board* (*CSAB*). Currently, CSAB serves as a participating body of ABET with two members on the ABET Board of Directors. It is the lead society within ABET for accreditation of programs in computer science, information systems, and software engineering, and is a cooperating society for accreditation of computer engineering. Accreditation activities once belonging to the Computer Science Accreditation Commission (*CSAC*) are now conducted by the Computing Accreditation Commission (*CAC*) of ABET with program accreditation responsibilities in computer science and information systems. The Engineering Accreditation Commission (*EAC*) is responsible for the accreditation of programs in software engineering and computer engineering. Current member societies of CSAB are the Association for Computing Machinery, Inc. (*ACM*), the Institute of Electrical and Electronics Engineers, Inc.–Computer Society (IEEE-CS), and the Association for Information Systems (*AIS*).

The objective of accreditation is to determine that an educational program meets minimum quality standards. It is not, in any sense, a warrant or guarantee of high quality, regardless of the multiattributed approach one might take to quality definition. A standard ABET definition of engineering is that (42) "Engineering is that profession in which knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind. A significant measure of an engineering education is the degree to which it has prepared the graduate to pursue a productive engineering career that is characterized by continued professional growth." It may appear at first glance that there is not much of a focus on the humanities and social science components of general education in this definition. However, the ABET annual reports proceed to delineate outcomes of an engineering education in a very meaningful manner that strongly include this focus. These five outcomes, clearly valuable for outcome assessment purposes, are as follows:

1. An engineer should have the ability to formulate and solve, in a practical way, those problems of society that are amenable to engineering solution.
2. An engineer should have a sensitivity to those socially relevant technical problems that confront the engineering profession.
3. An engineer should have an understanding of the ethical characteristics of the engineering profession, and professional practice.
4. An engineer should have an understanding of the engineer's responsibility to protect both occupational and public health and safety.
5. An engineer should have the ability to maintain professional competency through a lifetime of learning.

Thus, the ABET criteria are generally cognizant of the ingredients of a sound general education. It is interesting that the word *design* does not appear in either the definition or the listing or desirable outcomes, nor does the ubiquitous role of the computer and information technology. Design abilities are clearly needed, however, to achieve the five outcome objectives and are, therefore, implicitly included. Moreover, this is a very critical focus for engineering education and ABET accreditation effort. A major contemporary ABET trend is certainly that of providing an enhanced focus on engineering design for innovation (43).

To become accredited, ABET indicates that engineering programs must demonstrate that students in these programs attain abilities to:

1. apply a knowledge of mathematics, science, and engineering
2. design and conduct experiments, and analyze and interpret data
3. design a system, component, or process to meet desired needs within appropriate constraints
4. function on multi-disciplinary teams
5. identify, formulate, and solve engineering problems
6. use the techniques, skills, and modern engineering tools necessary for engineering practice
7. communicate effectively and
8. engage in life-long learning.

In addition, ABET suggests that students should have an understanding of professional and ethical responsibilities, a broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context; and a knowledge of contemporary issues associated with these such as to be professionally competent.

Further, it indicates that accreditable programs must include:

a. one year of a combination of college level mathematics and basic sciences (some with experimental experience) that is appropriate to the major discipline studied
b. one and one-half years of engineering topics, consisting of engineering sciences and engineering design that is appropriate to the field of study. There is a specific focus on engineering design-as a process of devising a system, component, or process to meet desired needs–here. a general education component that complements the technical content of the curriculum and which is also consistent with the program and institution objectives.

All of the program is expected to provide depth and balance. Faculty quality, institutional commitment to the program, laboratory facilities, library faculties, and other concerns are also evaluated.

Almost all development of curricula for undergraduate programs in engineering in the United States is based on these criteria. These lead to a more or less standard electrical engineering curriculum that is relatively ubiquitous in terms of specific required courses across electrical engineering programs in this country. As of early 2006, for the 2005 accreditation year, ABET has accredited 2,700 programs at more than 550 colleges and universities nationwide in applied science, computing, engineering, and technology education, Some 28 professional societies are ABET members in early 2006. For the 2005 accreditation year, there were a total of 1,759 ABET basic-level, or undergraduate, accredited programs of engineering, and 23 graduate programs, at 357 institutions in the United States. Of these, the largest number, 299, are undergraduate programs in electrical (and electronics) engineering. These are 3 accredited graduate level programs. Computer engineering had 180 accredited undergraduate programs and 2 accredited MS programs. The very small number of accredited graduate level programs is not unusual when it is realized that a department with both a graduate and undergraduate program would naturally much prefer to seek undergraduate-level accreditation, and ABET will presently accredit a program at only one level. This makes separate graduate-level accreditation proscribed, as few institutions would willingly not have their undergraduate program denoted as being accredited by ABET.

ABET has undertaken a number of initiatives, such as *Engineering Criteria 2000* (44), which is composed of eight criteria that are intended to emphasize quality and preparation for professional practice, to enhance engineering educational efforts. For example, The criteria retain the traditional core of engineering, math, and science requirements. However, the work also places importance on formal efforts that stress teamwork, communications, and collaboration, as well as global, economic, social, and environmental awareness.

There was also an outcomes-assessment component requiring each engineering program seeking accreditation or renewed accreditation to establish their own internal assessment process.

The criteria associated with the basic level accreditation in *Engineering Criteria 2000* address several basic areas of concern in engineering education (44): students, program educational objectives, program outcomes and assessment, professional components, faculty, facilities, institutional support and financial resources, program criteria, and cooperative education criteria.

Thus it can be seen that the ABET accreditation process is a voluntary system of accreditation that assures that graduates are prepared to enter and continue the practice of engineering. It also stimulates improvements in engineering education, encourages new and innovative approaches to engineering education, and identifies these programs to the public.

Each degree program has specific requirements that are to be satisfied in addition to the general criteria just stated. The program criteria for electrical, computer, and similarly named engineering programs were submitted by the Institute of Electrical and Electronics Engineers, which is the responsible participating professional society. They apply to engineering programs that include electrical, electronic, computer, or similar modifiers in their titles. The structure of the curriculum must provide both breadth and depth across the range of engineering topics implied by the title of the program. Also, graduates must have demonstrated a knowledge of probability and statistics, including applications appropriate to the program name and objectives. In addition, graduates must have a knowledge of mathematics through differential and integral calculus, basic sciences, and engineering sciences as necessary to analyze and design complex devices and systems containing hardware and software components, again as appropriate to the objectives of the program name.

The curricular specifications indicate that graduates of programs that contain "electrical" in their title must have demonstrated a knowledge of advanced mathematics, typically including differential equations, linear algebra, complex variables, and discrete mathematics, and that graduates of programs that contain "computer" in the title must have demonstrated a knowledge of discrete mathematics.

These accreditation criteria are based on the premises that

- Technology has been a driver of many of the changes occurring in society over the last several years
- It will take on an even larger role in the future
- The engineering education accreditation process must promote innovation and continuous improvement to enable institutions to prepare professional engineers for exciting future opportunities

These criteria are focused on ensuring competence, commitment, communications, collaboration, and the courage needed for individual responsibility and integrity. These, augmenting the usual listing of competence and assumption of individual responsibility as the two traditionally accepted key characteristics of a professional, might be accepted as the new augmented attributes of a mature professional. They should truly support the definition, development, and deployment of relevant, attractive and connected (quality) engineering education that will:

- Include the necessary foundations for knowledge principles, practices, and perspectives
- Integrate these fundamentals well through meaningful design, problem-solving, and decision-making efforts
- Be sufficiently practice oriented to prepare students for entry into professional practice
- Emphasize teamwork and communications, as well as individual efforts
- Incorporate social, cultural, ethical, and equity issues, and a sense of economic and organizational realities—and a sense of globalization of engineering efforts
- Instill an appreciation of the values of personal responsibility for individual and group stewardship of the natural, technoeconomic, and cultural environment
- Instill a knowledge of how to learn, and a desire to learn, and to adapt to changing societal needs over a successful professional career

The three classic steps leading to the designation of a person as a "professional" are:

1. A comprehensive and appropriate education that enables mastery of a body of specialized and relevant knowledge
2. A period of apprenticeship followed by a title or license to enable at least restricted professional practice in the area of specialization, according to a code of ethics
3. A professional organization with the power to regulate itself and impose standards of conduct and sanctions against incompetent or unethical persons or groups who would practice the profession

These three classic characteristics of a professional lead to several functional characteristics of professionals. Engineering is a professional activity, and standards and practices in engineering education must conform to these notions. Thus the content in this section becomes an inherent part of the objectives for an engineering school. They lead to such important activities as curriculum design. Additionally, they imply a subset of criteria for evaluation and outcomes assessment of programs and they become critical success factors for students in these programs. Importantly also, they bring into focus the need for a balance among studies involving knowledge practices, principles, and perspectives, and for the need to ensure that graduates are capable at knowledge integration as well as understanding of subject matter in depth.

SUMMARY

We have presented a wide-scope discussion of engineering education. We have discussed the emergence of electrical engineering as a discipline, the evolution of electrical engineering education as preparation for professional practice as well as for the development of knowledge principles through research, contemporary concerns relative to educational quality and responses to these, and educational needs and accreditation standards for the 21st century. A flowchart of interactions of electrical engineering education would show a very large number of linkages across many related elements, thereby indicating that engineering education itself is a system of large scale and scope. Our discussion is necessarily wide scope in that electrical engineering education itself is necessarily wide scope.

An electrical engineer must surely understand the principles of the natural and mathematical sciences. They must have this understanding in order to know how to use these sciences to produce cost-effective electrical systems and also to have the background necessary to retain intellectual currency throughout a lifetime of continued learning. The purpose behind the engineering of electrical systems is the development of products that are successful in the marketplace through fulfillment of societal needs. Technological, organizational, and societal change are the order of the day, just as they have been throughout history. If these changes are to be truly effective, over the long term especially, they must serve societal needs. This suggests that change needs necessarily to be guided by principles of social equity and justice as well as by concerns for sustainable development and marketplace competition. There is strong evidence that this needed guidance does not always occur and that the hoped for productivity gains from technological advances may be elusive (45–47). This evidence provides the mandate for a major component of the social and behavioral sciences, and the political and policy sciences, in engineering education and in engineering practice as necessary ingredients for success. It also provides a mandate for major integrative knowledge components in engineering education and for educational accreditation standards that reflect these needs, as recognized in the reengineering efforts for education and engineering education suggested by a large number of the sources cited here.

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