EDUCATIONAL TRENDS

This article on trends in engineering education considers some of the important influences on engineering education during the last fifty years. It examines the studies of engineering education commissioned over the years, starting with the Grinter report of the 1950s. It looks at changes in educational philosophy, industry–university interaction, student issues, such as enrollment and diversity, and concludes with a short discussion of a very significant issue of the times, the role of academic freedom, tenure, and posttenure reviews.

STUDIES OF ENGINEERING EDUCATION

At the end of World War II, the US Congress made a decision that was to have far-reaching effects on engineering education, indeed on all of higher education. This decision was popularly called "The G.I. Bill." It gave all returning veterans the opportunity to receive four years of university education. The veterans took advantage of the program, and soon engineering education classrooms were crowded. The students were mature, motivated, and set very high standards for themselves and the educational institutions. The effects of the G.I. Bill are probably exceeded only by those of the Morrill Act which established the land grant system of colleges and universities in the USA, when educational legislation is considered.

By 1950, the veterans were completing their degrees, and, as enrollments dropped and stabilized, engineering educators began to address the concerns that were so apparent during World War II. Too many engineers were unable to extend their knowledge to do the basic work needed to develop new technologies needed for war. Instead, the fundamental work was done by scientists. However, the engineers were able to take the basic work done by others and turn it into devices and systems needed for the war efforts.

The Grinter Report

Engineering education has always been introspective and willing to evaluate itself. The result in this case became known as The Grinter report (1). This study set the stage for nearly four decades of engineering education, both graduate and undergraduate. It led to programs with a strong engineering science content, a well-defined base in mathematics and basic science, and a clear emphasis on the social sciences and humanities. It led to programs that attracted engineering students to North America from around the world. It led to a period of rapid economic development on nearly every continent.

As engineering educators implemented the Grinter Report's recommendations, the Space Age began in 1957. The first satellites and orbital vehicles, some with human occupants, were launched. The first Moon landing occurred on July 20, 1969. For engineering education, the decade was marked by rapid implementation of the Grinter provisions and expansion of engineering research by universities across the United States. This combination led to a rapid expansion in technological knowledge and development and a wide variety of new products and services.

The QEEP Report

Concerns with the programs began to emerge in the 1980s. In the early 1990s, some of the tenets of the Grinter report and its implementations were being questioned, and new studies were undertaken. The 1986 study, known as the "Quality of Engineering Education" (QEEP) study (2), makes recommendations in four major areas. In faculty development, the study recommends more industrial experience for faculty and recommends that faulty bring such experience to the classroom. It also recommends increasing the relevance of an engineering education to the demands of the modern world and calls on the Accreditation Board for Engineering and Technology (ABET) to strengthen its faculty criteria with these factors in mind.

A second part of the study calls for making faculty development a structured process, not the ad hoc process it has always been. Universities, ABET, the American Society for Engineering Education (ASEE), Government, the National Academy of Engineering, the Foundations, Professional Societies, and Employer Organizations were charged with contributing to this process. Many of the agencies took the recommendations seriously and began to develop responsive programs.

The third part of the study deals with educational technology. It considers the role of the computer and of television and makes some very important and far reaching recommendations. Many of these have been implemented. It did not, however, foresee the rise of the Internet and the World Wide Web and their effects on education and the university in general.

The fourth section deals with the undergraduate laboratory. It points out two major problems, inadequate funding for equipment, and the heavy reliance on teaching assistants for laboratory teaching. These problems persist today. It foresaw the role of laboratory instruction in developing communications and teaming abilities, which have really become important in the past few years.

THE NATIONAL SCIENCE FOUNDATION COALITIONS

Engineering Coalitions

In 1989, the National Science Foundation called for and received proposals for programs to implement the recommendations, especially of the QEEP project. The call was for a group of universities to work together to effect the types of change called for in the report. The universities were to be a group diverse in size, support base, and clientele. The historically black colleges and universities (HBCU) were to be included. The institutions could be geographically proximate or nationally dispersed. The projects were to last five years.

By 1996, eight coalitions involving 60 colleges and universities were in place (8). Each had its goals or themes. The first two were formed in 1990. The Synthesis Coalition (California State Polytechnic University, San Luis Obispo; Cornell University; Hampton University; Iowa State University; Southern University; Stanford University; Tuskegee University; and the University of California at Berkeley) engaged in pioneering work in the delivery of educational materials and in the synthesis of knowledge for problem solving. The ECSEL Coalition (City College of New York, Howard University, Massachusetts Institute of Technology, Morgan State University, Pennsylvania State University, University of Maryland, and the University of Washington) emphasized design across the curriculum.

Two more coalitions were formed in 1992. The SUCCEED Coalition (Clemson University, Florida A&M University and Florida State University; Georgia Institute of Technology; North Carolina A&T State University; North Carolina State University; University of Florida; University of North Carolina, Charlotte; and Virginia Polytechnic Institute and State University) took on the responsibility of developing "Curriculum 21," which is intended to bring together the engineering and engineering education processes. The Gateway Coalition (Case-Western Reserve University, Columbia University, The Cooper Union, Drexel University, Florida International University, New Jersey Institute of Technology, The Ohio State University, University of Pennsylvania, Polytechnic University, and the University of South Carolina) is charged with doing research and development in integrative curricula.

The fifth and sixth coalitions were approved in 1993. The Greenfield Coalition includes Central State University, Lawrence Technological University, Lehigh University, the University of Detroit, the University of Michigan, Wayne State University, and a virtual university operated at HOPE's Center for Advanced Technology in Detroit, called FOCUS. It also includes industrial partners and is intended to study new methods and to develop new programs for manufacturing education. The Foundation Coalition is composed of Arizona State University, Maricopa Community College District; Rose–Hulman Institute of Technology; Texas A&M University, College Station; Texas A&M University, Kingsville; Texas Woman's University; and the University of Alabama. Its vision is to create an enduring foundation for continuing development and lifelong learning by students. Its goal is to integrate subject matter within the curriculum, incorporate cooperative and active learning, and use technology-aided education and continuous assessment of outcomes.

The final two were formed in 1994. One is known as the Academy (or the Engineering Academy of Southern New England), and it includes Central Connecticut State University; Connecticut Community Technical College System; Hartford Graduate Center; the University of Connecticut; the University of Massachusetts, Amherst; the University of Massachusetts, Lowell; and the University of Rhode Island. Its primary goal is to elevate the position and perception of manufacturing in both universities and industries. It focuses primarily on postbaccalaureate education. The final coalition, SCCEME (The Southern California Coalition for Education in Manufacturing Engineering) includes California State University, Fullerton; California State University, Long Beach; California State University, Los Angeles; the University of California at Los Angeles; and the University of Southern California. It also involves manufacturing and features development of interuniversity programs of undergraduate manufacturing engineering education.

Coalition Impact

The National Science Foundation has taken several steps to ensure that the knowledge developed by the coalitions is widely disseminated to and evaluated by the engineering educational community. It has organized plenary sessions and poster presentations at the annual "Frontiers in Education" conference (8) and at the annual conference of the American Society for Engineering Education (9). It has sponsored other conferences and involved coalition participants (3). These events have always been well attended, and the ideas presented have been widely discussed and considered by those in attendance and their colleagues with whom they shared the ideas. Few if any of the engineering programs in North America, especially the United States remain unaffected by the coalitions and the educational research and development done by coalition members.

OUTCOMES ASSESSMENT IN ENGINEERING EDUCATION AND ACCREDITATION CHANGES

Three Studies in 1994

Three additional studies were released in 1994 (3–6). Additional studies were made by other groups and are cited in the bibliographies of the references cited. The three 1994 studies have much in common, though they use different clientele and different methods. They were performed by the National Science Foundation (NSF), the Deans Council of the American Society for Engineering Education, and the National Research Council (NRC). The NSF study encouraged development of more diversity in engineering programs, defining this word broadly to include diversity of people and of experiences. It pointed out the centrality of students to the venture and encouraged faculty to be more active in designing the totality of educational experiences. It urged moving from predominately lecture classes to active learning. It encouraged engineering educators to develop broad, flexible curricula.

The Deans Council Study pointed out that engineering programs must be relevant, attractive, and connected. The programs must be relevant to the lives and careers of students and prepare them to contribute around the world over a lifelong, changing career. The programs must attract the best students from all groups of society. The programs must be connected to the needs, issues, and concerns of the broader community. There must be substantive partnerships between colleges of engineering and other educational institutions and with government and industry.

The NRC study predicted that future engineering programs will be designed to meet the demands of present and future engineering workplace challenges and life in an increasingly complex society. Such programs will include all necessary fundamentals but exclude redundant material, integrate design with fundamentals, be practice-oriented, emphasize both teamwork and individual effort, build a sense of social and business context, prepare graduates for entry into professions, such as law and medicine, instill a desire for lifelong learning, and prepare students for graduate study.

The 1996 Study

The 1996 study deals primarily with assessment (7). In this sense it follows the previous studies and takes steps toward providing the engineering education community with tools and methods for self-evaluation. It brought together five organizations with mutual interests in assessment activity. These include the American Society for Engineering Education (ASEE), the Accreditation Board for Engineering and Technology (ABET), the National Council of Examiners for Engineering and Surveying (NCEES), the ASEE Engineering Deans Council (EDC), and the National Society of Professional Engineers (NSPE) (8).

The report recommends that the following qualities be considered in designing an assessment program for any degree-granting engineering educational unit:

1. institution-specific mission and goals
2. institutionwide, longitudinal assessment programs
3. professional (ABET) accreditation
4. broader career goals of students and graduates
5. cost factors.

The report proposes assessment ideals, including the improvement of student learning and development, a focus on undergraduate (and, separately, graduate) education, educational breadth, relevance to practice and citizenship, validated measures of desired outcomes, comparisons with other programs, accommodation to future needs, and cost effectiveness.

The report goes on to point out that no one assessment tool is likely to suffice. Rather, an array of devices is needed. The report suggests that three independent measures of most qualities may be needed. Measurement tools may include student data, such as transcripts, portfolios, and videotapes of presentations. Other tools include performance of graduates on national examinations, though these are seen as having limited value with the present examinations. The most powerful tools are surveys designed for this purpose as part of self-analysis. The same conclusion is reached for assessing the performance of students after graduation.

ABET Criteria 2000

As the various studies were being conducted and preliminary analyses made of the data, it became apparent to the leaders of the Accreditation Board for Engineering and Technology (ABET) that the criteria for professional accreditation of engineering programs in the USA need major changes. Because of the international ties of ABET, the effect would extend beyond the United States. E. W. Ernst discusses accreditation substantially in a companion article. The discussion here is confined to points deemed essential to putting the process into the context of this article.

The concerns with the existing criteria, which substantially followed from the Grinter Report, were that they were too prescriptive, the process was too expensive, the criteria were becoming obsolete, and the process itself needed major changes. Although the process was changing in ways to reduce the intensity of these criticisms, more rapid change was needed. Universities and industry both supported change. The result was a draft of a totally new set of criteria, which have become known as "Criteria 2000" or "EC 2000." ABET is testing the criteria experimentally in 1996 and in 1997 and will use the new criteria optimally in 1998, 1999, and 2000, with full implementation in 2001.

Criteria 2000 are written primarily in terms of outcomes assessment. The criteria place the responsibility on an institution for identifying its mission, goals, and objectives, and for showing that its program leads to baccalaureate engineers who exhibit the desired characteristics. The curricular specifications are minimal, though they do not allow an institution to develop a program with an engineering title that is not engineering. Criteria 2000 are a major reason for the impetus for studying outcomes assessment techniques in the late 1990s. Reference (9) describes one successful technique for outcomes assessment in an undergraduate program. Reference (10) describes an effective use of alumni in outcomes assessment, and (11) describes very carefully a model for institutional planning for outcomes assessment.

An Assessment Plan

The following eight-step approach to developing an effective assessment plan is given by Rogers and Sando (12):

1. Identify goals. (What is to be achieved?)
2. Identify specific objectives for each broad goal, and state the circumstances under which you will know whether or not the goal has been achieved.
3. Develop performance criteria for each objective. (What will students be able to do, to be, or to possess when the goal is attained?)
4. Determine the practices to achieve the goals. (What will be done to achieve the goals and objectives? How might practices be modified in response to feedback?)
5. Select assessment methods for each objective, and choose data collection methods.
6. Conduct assessments. Use specified methods to collect the evidence, and analyze the evidence in comparison with performance criteria.
7. Determine feedback channels that provide timely information to enable continuous improvement, decision making, and evaluation.
8. Evaluate whether or not performance criteria were met and objectives achieved. Typically, this last step occurs during the continuous improvement process (formative evaluation) and at the end of the project (summative evaluation).

Assessment Action Recommendations

The assessment study concludes with the following five recommendations to all engineering programs, though it recognizes that there are still many unanswered questions with regard to assessment. It appears that it will be necessary to apply the continuous improvement process to the assessment activity itself.

1. Each engineering program should develop an appropriate assessment program using the *ABET Engineering Criteria 2000* in conjunction with criteria specific to individual institutional and program goals.
2. NSPE and NCEES should actively encourage and participate in the continuing discussion of the relationships of engineering education to licensure and practice.
3. ASEE and ABET, in cooperation with the Deans Council, should coordinate the efforts of selected institutions and the major employers of the graduates of those institutions to identify and report the possible relationships between performance as a student and subsequent professional performance.
4. ASEE should seek resources to act on the resolution of the Deans Council which "calls for a continuing forum for the development and analysis of assessment methods and measures of learning appropriate to the stakeholders in engineering education." Such a forum could help the engineering community implement program assessment by disseminating best practices, identifying measures associated with educational outcomes, and sharing experiences of specific institutions and programs.
5. ASEE should establish a clearninghouse for a nationally shared database on engineering educational program assessment measures. Data should be collected, aggregated, and reported at the program (or discipline) level.

FACTORS AFFECTING ENGINEERING EDUCATION

Institutional Changes

The preceding paragraphs point out the vast changes that have occurred in engineering education in the last decade. The changes largely result from the self-analysis in which engineering education has always engaged. If the goal of outcomes assessment is continuous improvement, then engineering education has been following the tenets of continuous improvement for nearly a century, and the last decade is no exception. Although the changes result from self-analysis, they are not independent of institutional, technological, and international forces at work throughout society.

In the United States and around the world, universities have become large, multifaceted, and quite visible. This is true of both public and private universities. The clientele of the universities, including government, taxpayers, donors, students, and industries, are demanding increasing accountability by the universities for their expenditures. Mandatory retirement has been eliminated, though no evidence exists that very many people are working longer than they should. In fact, many valuable faculty are choosing early retirement. The institution of tenure itself is under scrutiny, especially in professional schools, such as engineering.

One result of these pressures is the drive to reduce the number of credit hours required to earn an engineering degree, or for that matter, degrees in other disciplines. Part of the pressure comes from parents who wish to reduce the cost of an education. Some comes from taxpayers and governing bodies. This seems counterproductive in the face of rapid technological development, but it does require institutions to focus on their missions and to articulate carefully their goals and objectives. This drive is consistent with outcomes assessment. It forces faculty to be sure that topics studied are really needed, and that they will serve the student well. It probably is also true that the amount of study required to earn a unit credit has slowly risen over the years.

Technological Changes

Technological changes continue at a rapid pace. Much of the change has been caused by the graduates of the engineering programs in the United States and elsewhere, so it is difficult to say that the programs of recent years are ineffective. The technological changes, in fact, have led to major societal and engineering education changes.

One, alluded to in the previous paragraph, is the fact that it simply is not possible to discuss in the engineering classroom all of the technological developments nor to predict accurately what is likely to come in the near future. It always makes a class interesting to discuss current developments, but it may not be the most effective educational method. It is also true that students are often more comfortable with some technologies than the faculty, which leads to a certain tension in the classroom. Students also have grown up in a period heavily emphasizing technological systems, such as television, computers, instantaneous communications, and rapid transportation. No doubt this affects their learning styles substantially.

International Considerations

One of the most apparent changes in engineering education in the last decade has been the rapidly increasing importance of international factors. Engineering itself has become international, as students travel to a variety of countries to study and engineers practice around the world. The companies that employ engineers work around the world, and they recruit engineers from many nations. Products and engineering services are designed and developed for a world market. Products designs are completed in one country and transmitted electronically halfway around the world for manufacture, and the completed products are then marketed worldwide.

Engineering with Information

Traditionally, engineers have worked primarily with energy and materials. The knowledge that they accumulated was stored in handbooks, and current information was available in manufacturer's literature. Knowledge and information have always been important to the engineer, but the study and the practice of engineering have focused on materials and energy.

The digital computer has changed this characteristic of engineering. Engineers now practice as much with information as with energy and materials. Although most evident in electrical and computer engineering, it is true in all engineering fields. Much attention must be given to the design of information systems so that complete and accurate information is readily available early in the design phase of a product or service, and this is fully as important as proper choice of materials and use of energy. In fact it is essential to the proper choices.

ISSUES IN ENGINEERING EDUCATION

Cooperative Educational Programs

The pressure on universities to reduce the number of credits required for an engineering degree has been mentioned. Some of this pressure has come from industry. Concurrently, industries have expanded their cooperative programs (coop). In its basic form, a coop program (not to be confused with cooperative learning) includes a traditional four-year engineering program interleaved with structured industrial experiences. The length of industrial experience is normally a year or more. A typical pattern might be a summer assignment following the sophomore year, a semester and a summer assignment after the first semester of the junior year, and a summer assignment in the senior year. Many other patterns are possible.

Included in this expansion are international coop experiences, and these are proving to be a valuable part of the engineering education enterprise. Much of this change has been apparent starting in 1996. The anecdotal data available at present suggest that institutions which traditionally have had about 10% of their students involved in coop programs suddenly have 60–75% participation, and employers who would like to have even more coop students.

Industrial Partnerships

Besides coop programs, universities and industry are forging other partnerships. Industries are encouraging their senior people to serve on Industrial Advisory Committees of Colleges of Engineering, and these people are making major programmatic contributions. Their ideas are being carefully considered and often implemented. Their ideas relate to course and curricular content, space and facility use, finances, research development, and helping to develop public support (13–15).

Research projects in the university supported by industry are becoming particularly important and often include undergraduates. One reason is that the resources supplement the public monies available to universities, funds that have become scarcer in recent years. The projects undertaken are challenging and, in most cases, involve leading-edge technology. Major needs are being considered. One difficulty with many of the projects is the need for industry to keep its proprietary information confidential, which contrasts with the need of the university for openness and publication. As faculty advancement depends in large measure on publication, this is a major problem. It is being resolved in a case-by-case, university-by-university method.

Another reason for the importance of industrially sponsored research is the fact that it brings the faculty into close contact with industry. This contact enhances their engineering background and enables them to be more effective in the classroom and learning laboratory as they educate the next generation of engineers. Many of the research projects are closely tied to the coop programs mentioned earlier and to the graduate coop programs emerging on some campuses.

Many of the industry–university partnerships are characterized as joint ventures. The two agencies agree to cooperate to develop a marketable product or service, with appropriate provisions for sharing the risk and gain. Many of the ventures involve students. Activities such as these provide an invaluable opportunity for students to experience the thrills and frustrations of engineering while still students, and usually they indicate that their motivation to continue study toward baccalaureate and advanced degrees is strengthened.

ACTIVE LEARNING AND COOPERATIVE LEARNING

William L. Everitt, former Dean of Engineering at the University of Illinois, said on many occasions that "engineering is not a learned profession, it is a learning profession." It is true that the successful engineer today must continue to learn throughout a career. Often this is called "lifelong learning." Being a lifelong learner requires that the engineer wants to continue to learn and to have the skills to accomplish the task. Helping students develop this skill is, in part, a responsibility of the engineering faculty.

Active Learning

The lecture/recitation/laboratory method has been used in traditional classes in many disciplines, including engineering. In this classroom, the faculty member presents material and guides discussion. Further discussion takes place in the recitation section. Laboratory work serves the dual purpose of teaching students to become experimentalists and to reinforce the lecture material. As the class grows larger, students are engaged but often only to a limited extent. Much of their learning takes place individually outside the classroom. Formerly, the laboratory was probably the principal learning arena for the engineering student, but, as programs have reduced credits and as laboratories have become more expensive, the time and effort devoted to laboratory instruction has decreased.

Active learning, sometimes called interactive learning or interactive instruction, is a process of developing a framework in which students interact with the material in the classroom. The faculty functions more as a manager and resource than a presenter of information. Students are encouraged to seek information on their own or in groups, with guidance from the faculty. In some institutions, faculty are learning these techniques from colleagues in the Colleges of Education, where substantial research into learning methods has taken place (16). The most important characteristic of active learning is that the students are and must be actively involved or engaged with the material while in the classroom, understanding as much as possible why they are doing what they are doing, and seeking help from other sources, including the faculty, when they lack a specific item of knowledge (17).

Cooperative Learning

The most effective way to achieve the goal of active learning is to use the technique of cooperative learning. Sometimes called "teaming" or "collaborative learning," cooperative learning also meets a need of contemporary employers for graduate engineers who are skilled in working with other people. The basic idea of cooperative learning is quite simple, but its implementation requires a lot of skill and practice (18).

Cooperative learning requires grouping students in a class into groups of 2 to 4 people. These students sit together and usually work together inside and outside the classroom. The students work cooperatively on the assignments given and shared roles of leadership, recording of results, and other necessary tasks. In many cases, the group turns in written assignments, and each member receives the same grade. In some cases, students comment on colleagues, and this information modifies grades to some extent. To encourage teamwork, many instructors give bonus points on examinations to all members of a group when all earn grades above some threshold value. Because grading "on the curve" tends to encourage competition among students, it is necessary to grade on "absolute standards."

A collection of students is not necessarily a team. Faculty find that they must put some effort into helping the students function as a team. Reference (18) suggests the following five basic elements of cooperative learning:

1. Positive interdependence. The students must be convinced that they need each other and that it is in their best interests to work together. With beginners, students need to be assigned roles, and in some cases, faculty make information available only to one member in a group.
2. Face-to-face promotive interaction. Students are encouraged to help each other by sharing and encouraging each other. When possible, they pass on their knowledge to classmates outside the group. Students talk through solutions to problems. It is self-defeating for each person to work alone and to come to a meeting to present individual solutions.
3. Individual accountability. Though the students work together, each is responsible for learning. Individuals may be tested regularly or called on to recite when the class size permits.
4. Interpersonal and small group skills. All members of a group need to have a basic set of skills, including time management, communicating ability, willingness and ability to resolve conflicts, and decision making. There must be mutual trust and respect among all members. If these are not present, the group will not function and must be reorganized.
5. Group processing. Members need to put some effort into discussing how well they are achieving their goals, and the instructor must be involved in this activity. Feedback must be given.

Students have always worked together, but optionally. In most cases, these new techniques work well for most of the students. Students, however, are busy, and finding common meeting times and places is a chore for some. This turns out to be especially difficult when several instructors are using the techniques and a student is a member of several groups. There are always a few students who resist the idea, and they require individual consideration.

INTEGRATED CURRICULA

A traditional engineering program has been composed of 32 to 40 courses (semester system) or 48 to 60 courses (quarter system). With few exceptions, engineering curricula are characterized by a rigid prerequisite structure. Instructors assume a consistent background for all of the students in a class and design a course to build on that background. This structure achieves a high level of integration, but to do this, it requires that students put a lot of effort into the integrating effort, though they are often unsure how the pieces fit together. Because, increasingly, students demand a clear indication why study of particular topics is important, much research has gone into developing programs and curricula designed to improve the cohesiveness of a program and the learning by the students. One term that describes this effort is the "integrated curriculum" (19–22).

The basic idea of an integrated curriculum is simply described. In a traditional program, for example, physics and calculus are studied independently. The mathematics faculty presents ideas, such as the derivative and the integral of a function. Following that, the physics faculty defines concepts, such as velocity or current, in terms of the derivative, and concepts, such as voltage or work, in terms of the integral. When syllabi are such that the topics are covered closely together, and the physics follows the mathematics, then the process works well. But if the physics precedes the mathematics, or the topics are well separated in time, then full integration becomes much more difficult. The same problem continues in basic mechanics or electrical courses, which then depend on the physics.

In an integrated curriculum, the physics and mathematics faculty work together, presenting physical concepts and the mathematical tools needed to understand them. Often the classes are team taught, but, in other cases, the topics are very closely coordinated. Simultaneously, the engineering faculty is presenting the core ideas of the various branches of engineering, working closely with the physics, mathematics, and chemistry faculties, and others if necessary. Sometimes the phrases "just in time" or "need to know" are used to describe the process. Another term is "holistic thinking."

The idea can be extended. In senior design, students often need economic ideas and are faced with ethical decisions. They need to study reliability. This may be the time to introduce basic ideas of engineering economy, professional ethics, and statistics. Again, in the early years, engineering students are taught some of the basics of design, and, more important, given the opportunity to express their creativity, although they may not yet have all of the tools needed for industrial level design. By being given such problems, the studies indicate that they are encouraged to go beyond their basic classroom assignments and study material appropriate to their design problems. The integrated techniques are probably most effective in the early part of an engineering curriculum but find application throughout the program. It is important to note that the ideas are not limited to the technical parts of a curriculum but apply to all components of an engineering course of study.

LEARNING STYLES

Not all students learn the same way. Recognition of this fact has received new emphasis in the last fifteen years. Some of the reasons for this include the desire to increase retention of students, especially the outstanding students who are uncomfortable in a traditional engineering program, and the desire to attract and retain women and students from underrepresented minorities. Of course the most important reason is simply to be more effective as faculty and to educate better engineers. The basic idea is for the faculty member to understand one or more of the different models that explain how students learn and to design instructional experiences to meet the needs of all students. The similarities in the models are more important than the differences among them. Despite their individual learning styles, students in any of the groups can become outstanding engineers.

Kolb Theory

The Kolb theory (23–25) considers the ways in which people perceive and process information. Some people perceive information primarily by concrete experiences (CE), others by abstract conceptualization (AC). (These terms, and those that follow, represent continua between extremes, not absolute conditions.) Some people process information primarily by active experimentation (AE), others by reflective observation (RO). Kolb calls those "divergers" who perceive CE and process by RO. Those who perceive as AC and process as RO are called assimilators. Those, who perceive as AC and process as AE, are called convergers. Finally, those who perceive as CE and process as AE are called accommodators. Though no individual fits neatly into one of these four categories at all times and may move around significantly in different situations, the four characterizations do provide some useful insights.

Divergers. Divergers, also called imaginative learners, are given this description because they see concepts from different perspectives and generate ideas readily. They learn through discussion and want to interact personally with the faculty. Feelings are important, and they need to be convincingly shown why material being studied is important, to themselves and to others.

Assimilators. Assimilators like order, are detail-oriented, and follow directions carefully. They are also called analytic learners. They learn well in traditional classrooms and prefer to work alone rather than in groups. They see the instructor as the expert and authority figure. They like lectures, especially those that are well presented, organized, and complete. Because so much of education is organized in a way that assimilators like, other students adopt many of the characteristics of assimilators to succeed.

Convergers. Convergers, also called common sense learners, quickly move (converge) to the essence of a problem or situation. They test information and ideas and are interested in the practicality and usefulness of the information presented. They are active and are less interested in lecturing as a class style. They prefer laboratory classes and prefer to work alone rather than in groups. Their preferred teacher plays the role of a coach, one who permits the students to take an active role in their own learning.

Accommodators. Accommodators are so called because they take what they have learned and adapt it to new problems, usually showing a lot of creativity. Often they are called dynamic learners. They like interaction and like to take an active role in their own learning and self-discovery. They resent too much structure. Their ideal instructor is one who remediates, encourages, and evaluates, but also who remains in the background as much as possible.

Personal, individual inventories have been administered to many engineering students in both public and private universities. The data show that about 10% of the students are divergers, 40% are assimilators, 30 to 40% are convergers, and 10 to 20% are accommodators. The significance of these data is that, whereas 40% of the students are assimilators, for whom the traditional lecture is designed, 60% may be better served by extensive use of other techniques, especially those which promote active learning. This observation explains the rising importance of cooperative learning which, if used in conjunction with other techniques, allows educational experiences intended for all the students. As people mature, they have more interest in active learning experiences. This fact is important as engineering classes have more and more "nontraditional" students.

Myers–Briggs Type Indicator

The Myers–Briggs Type Indicator (MBTI) (26,27) is an instrument originally developed to measure, in part, whether an individual prefers to learn by sensing or intuition. Now the term usually refers to a measurement instrument that measures five axes of learning, including perception, information reception, reasoning progression, preferred learning processes, and preferred method of presenting materials. It thus has five axes, each with two extremes, and the possibility of 32 learning styles. While this does not suggest that faculty needs to segment their teaching into 32 distinct styles, it does suggest to many today that they need to alter presentations to reach many of the styles.

Sensing and Intuitive Learners. Sensing involves gathering of data through the senses, especially seeing and hearing, whereas intuition involves indirect perception by way of the unconscious, including hunches, imagination, and speculation. Most undergraduate engineering students are, at this stage of their development, sensors, wherereas most of the faculty are intuitors. Intuitors prefer use of symbols, theories, and principles, whereas sensors prefer facts, data, and experimental work. Laboratory courses appeal to sensors.

Visual and Auditory Learners. Engineering students may prefer to receive information verbally or visually. (There is a third method, kinesthetic, which plays little if any role in engineering education.) Visual learners prefer demonstrations, videos, computer animations, and diagrams. Auditory learners prefer lecturing and discussion. Because the process of writing equations on a blackboard is nearly always accompanied by speech, such a technique is considered primarily auditory.

Engineering students are visual learners, though most engineering education today is auditory. Recognition of this fact is one reason for the continuing research into the subject and the significant amount of time being invested in World Wide Web learning and other computer-based techniques.

Sequential and Global Learners. Some engineering students learn in a logical progression of principles, data, hypotheses, and new ideas, at a pace controlled in time. This is called sequential learning, and the students learn the material as it is presented. Such students can work with partial knowledge, going back over the ideas repeatedly until they master them.

In contrast, global learners absorb and assimilate ideas in large blocks. They are characterized as confused until the "aha moment." Suddenly, it seems, they understand the material well and are able to use it, often applying the ideas to quite difficult problems, and using the knowledge creatively. Unfortunately they may be easily discouraged and drop out prematurely. Because much of engineering education is structured for sequential learners, teaching global learners is a challenge to the faculty.

Active and Reflective Learners. Information must be processed into knowledge by the learner. Some do this by active experimentation, using the ideas, testing them, working with them. They like experimental work. They do not like lectures, but work well in groups. Reflective learners prefer to work alone and need time to think about the information presented.

It is important to recognize that this distinction differs from that between sensors and intuitors. Some sensors process information reflectively, others actively, and the same is true for intuitors. Cooperative learning, as the term is used earlier, incorporates some of the features of both active learning and reflective learning, which explains why it is such a powerful tool in the modern engineering classroom.

Inductive and Deductive Learners. Inductive learning is a reasoning process that proceeds from the specific to the general, whereas deductive learning proceeds from the general to the specific. Inductive learners look at data, measurements, and observations and from this try to determine the underlying structure. They infer principles. Deductive learners start with theories and principles and try to infer consequences.

Deduction is the natural teaching style, as it enables the faculty to start with basic principles and study the application of the principles. It gives the students a foundation for future study. But it is not necessarily the natural human learning style, especially for college-age students. People learn more by observation and experimentation and from that draw basic inferences. Much effort today is going into combining these techniques in the classroom, to accommodate all students and still provide a strong foundation for future learning by all of the engineers.

One of the difficulties of deductive teaching for students, is that, when a book author or a faculty member starts with a principle and proceeds through a long derivation to a conclusion, the student often believes that the process is automatic, not one with many stops and starts along the way. Certainly the first person to do the work did not find it automatic. The process can be intimidating for students, yet attempts to show students the stops and starts often come across as if the instructor does not know how to do the derivation. The inductive-deductive dilemma may be one of the most difficult for the engineering faculty in today's classroom.

ENROLLMENT, DEGREES, AND RETENTION

Undergraduate engineering enrollment in the United States was relatively constant from 1966 until 1976, when it increased rapidly, reaching a peak in 1986 (28,29). Since then, enrollment has declined but has been relatively constant for the last ten years. It is often more interesting to look at degrees granted annually. The number of baccalaureate degrees was substantially constant at about 40,000 from 1966 until 1976, when it rose rapidly to a peak of nearly 80,000 in 1986. Since then, the degree numbers have declined to a relatively constant value of just over 60,000 per year, and this number does not appear to be changing significantly. One effect of this constancy has been for colleges and universities to focus more effort on retention, increasing the fraction of the students starting an engineering program who finally earn an engineering degree.

At the graduate level, the number of engineers earning masters degrees has steadily increased over the interval 1966 until 1993 (there were two minor declines in this period). This number has gone from about 14,000 in 1966 to 28,000 in 1993. Many of these degrees are earned by students who combine work in government or industry with advanced study, taking advantage of more than 50 distance education and evening programs across the country. In electrical and computer engineering, the National Technological University now grants more than 200 masters degrees per year. Its primary delivery mechanism is satellite television, using courses from more than 40 major universities across the country. The number of engineers earning Ph.D.s first surpassed 1000 in 1962, and rose quickly to about 3500 in 1972. Then it fell to about 2200 in 1979, but since then has risen to nearly 6000 in 1993.

Demographics

The demographics of the baccalaureate graduates have changed. In 1966, approximately 1% of the graduates were female. By 1993, this number had risen to about 17%. A lot of effort has gone into developing programs to encourage young women to prepare for careers in engineering science while they are still in public schools. Summer workshops, careful and special advising, and programs to educate the faculty and majority group students how to avoid words and actions that make women feel uncomfortable have all played a major role. The Society for Women Engineers has been a major factor, as it provides role models for colleges and universities. Employers have also made special efforts to enhance the attractiveness of an engineering career to young women. At the graduate level, the fraction of women earning masters degrees has increased from 1% in 1966 to about 15% in 1993, whereas at the Ph.D. level, the number has increased from less than 1 to 9%.

Three groups traditionally underrepresented in undergraduate engineering programs are Native Americans, Hispanic Americans, and African Americans. Much effort has been devoted to increasing these percentages in recent years, including the coalitions of the National Science Foundation, the National Action Council for Minorities in Engineering (NACME), and special programs on the campuses of many colleges and universities across the country. Because of their efforts, the fraction of engineering degrees going to these three groups has increased from 2.9% in 1972–73 to 9.2% in 1994–95. However, these three groups comprise about 21% of the U.S. population, so the groups remain underrepresented.

Retention

Many engineering educators are focusing attention on retention or graduation rates, comparing numbers of graduates with numbers of entering first year students (3–6,8,29,30). Retention rates vary widely across the country and with the type of institution. Some of the private institutions report graduation rates as high as 95%, whereas the rates in public universities vary from 50 to 70%. Students drop out of engineering for many reasons, but the focus is on those students who, though they have the ability, lose interest for any of a variety of reasons. This problem may be more acute for underrepresented minorities and women, but not significantly so.

Many of the new techniques employed in engineering education have as one of their main goals that of improving graduation rates. This includes cooperative learning, cooperative programs (with industry), attention to learning styles, and more efficient curricula. Other techniques shown to be important are being sure that students have adequate financial resources, sometimes said to be the most important single reason for students dropping out. Special programs must be carefully targeted. Programs designed to provide academic support for "at risk" students must not seen as programs for underrepresented minorities, or vice versa. Programs must be accessible, and the people involved must be available when the students need them, not necessarily during normal working hours.

FACULTY DEVELOPMENT

The preceding discussions have identified many new techniques and skills needed by engineering faculty. Faculty need time and must expend much effort to learn cooperative learning, teaming, skills for working with underrepresented minorities, women, and international students, how to do outcomes assessment, how to teach larger classes effectively, and how to do scholarly research in education and in technical disciplines. Many universities are making these opportunities available and are positively encouraging all ranks of their faculty to participate.

At the same time, the faculty of our engineering schools and their graduates at all degree levels are doing exactly what they are expected to do, to advance knowledge and the level of technological development. This advancement is occurring rapidly, and the faculty must also keep up with their profession in addition to improving their effectiveness as teachers. These challenges are real, but meeting them is the reason most if not all faculty choose the academic career.

Industrial Experience

One of the concerns described in the studies mentioned earlier (3–5) is that a large portion of the engineering faculty have little or no industrial experience, especially at a level comparable to their university responsibilities. The faculty may have had summer assignments and have done some consulting, but many have not had the major responsibility for a complete design from the conceptual stage to production and marketing. Many see this as a weakness, and there is no doubt that those with good industrial experience are equipped to share these ideas with their students.

Industrial leaders recognize this concern, and many are working to improve the quality of engineering education by several efforts. The most important is to give selected faculty members opportunities to work in industry. Some assignments may be a summer in length, whereas others extend well beyond a year. The assignments are challenging and give the faculty member opportunity to work in several phases of the industrial process. Some are sending their outstanding engineers to the campus for a semester or a year.

These programs are not without problems. A faculty member or an engineer in industry, who finds employment relatively far from the home campus or corporate office, must move a family. In an era of two-career families, this is a major challenge. Assignments within commuting distance sometimes meet this need, but not all universities are located in or near industrial centers. Research programs and product developments may suffer. This problem is acute for young faculty members striving to earn tenure. Many of the programs are designed for faculty who have earned tenure and for engineers in industry who have advanced equivalently far along the ladder of achievement. A major concern is the academic emphasis on individual excellence, which contrasts with the industrial emphasis on teamwork. Universities are wrestling with this issue, but it is far from resolved, even though much research today requires teamwork and interdisciplinary activities.

Scholarship

An engineering faculty member must have, among other qualities, a desire for and a record as a scholar. Since World War II, the primary way a faculty member demonstrates scholarship is through research. Research has been important for the university, the nation, and the world, and for the agencies sponsoring it. Government agencies have sponsored most of the research, which has been targeted toward a variety of national needs. Research reports, conference presentations, and refereed publications are available for peer evaluation. To a faculty member, peer acceptance is crucial. The increase in engineering knowledge over this period has been remarkable.

The universities, however, have been severely criticized over this period by students, ruling bodies, and the public. The charge has been that the faculty have been involved in research to the detriment of their teaching and undergraduate teaching. No study has demonstrated that the leading researchers are ineffective teachers. On many campuses, teaching awards voted by students go to those who are active in research. But the criticism continues.

Changes are emerging in the research picture. More research is supported by industry and relatively less by government agencies. Industrial research is often proprietary, which inhibits timely publication of results. Industrial research has generally shorter periods for delivery of results than government agencies require. Universities are learning how to do industrial research and how to evaluate products, patents, processes, and publications. This major change has effects on tenure, to be discussed in the next section, and, when combined with public pressures, is requiring universities to rethink what they mean by scholarship.

The most significant effort dealing with scholarship was a book published by Ernest L. Boyer (31) in 1990. Boyer studied universities and the concept of scholarship. He defined the work of the faculty, so as to reflect the wide variety of responsibilities that the faculty has, and showed that all of the major activities have a strong element of scholarship to them. He defines four separate functions, namely the scholarship of discovery, integration, application, and teaching. After defining them, he goes on to suggest ways in which all forms of scholarship might be evaluated. These ideas are being considered across the country as faculty and university leaders become accustomed to them.

Scholarship of Discovery. The *scholarship of discovery* is defined as disciplined investigative efforts within the academy. This is research, which should be undertaken systematically but with the freedom of inquiry to pursue knowledge for its own sake, wherever the trail may lead. Such scholarship invigorates the academy and is central to the academic mission. It must be cultivated, supported, and defended. It is vital to our society and to all people in the world.

Scholarship of Integration. The *scholarship of integration* is characterized as interpretive, integrative, and interdisciplinary. It follows, in a sense, from the scholarship of discovery and includes doing research at the boundaries between fields ("overlapping academic neighborhoods"). It includes interpretation, or fitting one's own research and the research of others into larger intellectual patterns. The scholarship of integration looks at the meaning of results. It is quite difficult and challenging. It rarely can be done by individuals, as it requires collaboration in most instances. Its evaluation is difficult, but it is important to the academy and to all of society.

Scholarship of Application. The *scholarship of application* refers to scholarly activities proceeding out of research to make the results useful and uplifting for all of society. It may refer to applications of computers to medical systems to improve health or to electric power systems to increase reliability of such systems. Such scholarship is very demanding and usually requires a team effort to effect results. It is exemplified in today's college of engineering by the efforts to encourage technology transfer, the movement of results from the laboratory to the marketplace. Technology transfer requires careful attention on the part of the academy to ensure that the rights of the sponsors and the public are properly considered. While a few universities have had such activities for many years, many universities are now learning how to encourage the scholarship of application.

Scholarship of Teaching. The *scholarship of teaching* includes all of the activities a faculty must do to promote student learning (some have suggested it should be called the scholarship of learning). The teacher must be informed about the subject at hand and of interrelationships. The teacher must transmit knowledge and ideas and must also tranform and extend knowledge. The teacher must motivate the students to become learners themselves. The faculty does this by being learners themselves and exhibiting this behavior. In addition to the activities in direct contact with students, the scholarship includes preparation of textbooks, educational research, preparation of software, and laboratory materials. All of these are essential parts of the art and science of teaching.

In Boyer's book, the author goes on to discuss ways of evaluating these forms of scholarship and suggests that evidence must be gathered from at least three sources, self assessment, peer assessment, and student assessment. Across the country, promotion and tenure committees are struggling with these ideas and learning techniques for collecting the right data and performing rigorous assessments of the four forms of scholarship. Portfolios for faculty are emerging as one of the components of the evaluation and assessment process.

PROMOTION AND TENURE

A faculty member who is either doing research or teaching in a potentially controversial discipline may need a form of protection. Research may lead to results that challenge accepted positions or authorities. Teaching at the frontier of knowledge may require the faculty member to express ideas and research results that are unpopular for whatever reason. To protect the academic person from reprisals in such situations, the concept of academic freedom has developed, especially since the late 1930s. All faculty members have disciplines in which they are recognized as expert or authorities. When such faculty members express ideas, opinions, or research results within this discipline and do it in an academically responsible manner, academic freedom gives them the needed protection. Academic freedom is closely related to tenure, the granting of indefinite employment to a faculty member upon demonstrating appropriate scholarship and other characteristics.

Tenure

Granting indefinite employment to a person is a decision that the academy takes very seriously. In most cases, faculty members serve a probationary period of six years, near the end of which their records are examined by peers away from the campus, by students, and by colleagues on the campus. A few universities have probationary periods as long as nine years. Regardless of the length, all forms of scholarship are carefully evaluated, and, usually, secret votes among the faculty colleagues are taken. Recommendations are reviewed at several administrative levels before tenure is finally granted. Usually, but not always, the faculty member is also promoted in rank to Associate Professor. No good statistics on the fraction of nominees who actually earn tenure exist, but there is no question that the process today is long, arduous both for candidates and colleagues, and involves a lot of time and effort on the part of many people.

Posttenure Review

Not surprisingly, people not closely connected with the university have great difficulty understanding the concept of tenure. Few other professionals have or need a similar status. Many people see tenure as simply a lifetime contract and fear that many in the academy will “retire in place” after earning tenure. The elimination of mandatory retirement policies has exacerbated this concern, though no evidence exists that larger numbers of people are abusing the system.

In public universities, governing bodies are responding to this concern by mandating more stringent reviews of faculty than they believe have been taking place. The details vary widely across the country. Nearly all faculty already receive periodic (usually annual) performance reviews, and they also are continually receiving peer reviews from their colleagues on and off of the campus, who carefully read their latest research papers and textbooks. Governing bodies are asking for more. The process is called “posttenure review.” The term refers to a formal, periodic process for reviewing faculty members who have earned tenure, using standards comparable to those for earning tenure. Faculty committees on many campuses are studying the process with great care.

At the University of Minnesota, the Board of Regents has approved a new Promotion and Tenure document which contains a posttenure review section (32). This plan builds on annual reviews, and prescribes a process for working with those faculty members who receive less than favorable annual reviews. Each such person is to receive further evaluation by a peer group. This group may conclude that the unfavorable review is not unwanted, or it may recommend a variety of courses of action having to do with work assignments and performance. In extreme cases it can recommend reductions in salary and even the initiation of dismissal procedures. The process is very structured and contains many safeguards for all concerned, especially the affected faculty member. It is too soon to assess the impact of the new procedure. As this is one of the first, committees all across the country are studying their document, and it is likely that many universities will have such a process in place in the near future. Some may be more, some less stringent.

Tenure Concerns

As mentioned earlier, colleges of engineering are striving to enhance their industrial contacts. One technique used is to add to faculties engineers who have outstanding records in industry, records of patents, product development, project management, and systems design.

These people do not typically exhibit normal faculty credentials. Although many have taught in-plant short courses, they have not often taught university courses. They are discouraged or even prohibited from publishing in refereed journals for proprietary reasons, and they have little incentive because publication is not a part of their reward structure. Promotion and tenure committees are struggling with ways to recognize such contributions so that these new faculty members are properly evaluated but a tenured position is not immediately made available.

Another concern for people in some disciplines is how to properly work with tenured faculty when enrollment in disciplines becomes very small and programs are discontinued. Although all governing bodies allow dismissing faculty members in such situations, the universities try very hard to find appropriate new situations for the people. Arguing that a scholar in one discipline can become a scholar in a different discipline, they universities are designing programs for “study in a second discipline,” granting leaves, and providing other appropriate opportunities.

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EEG. See ELECTROENCEPHALOGRAPHY.