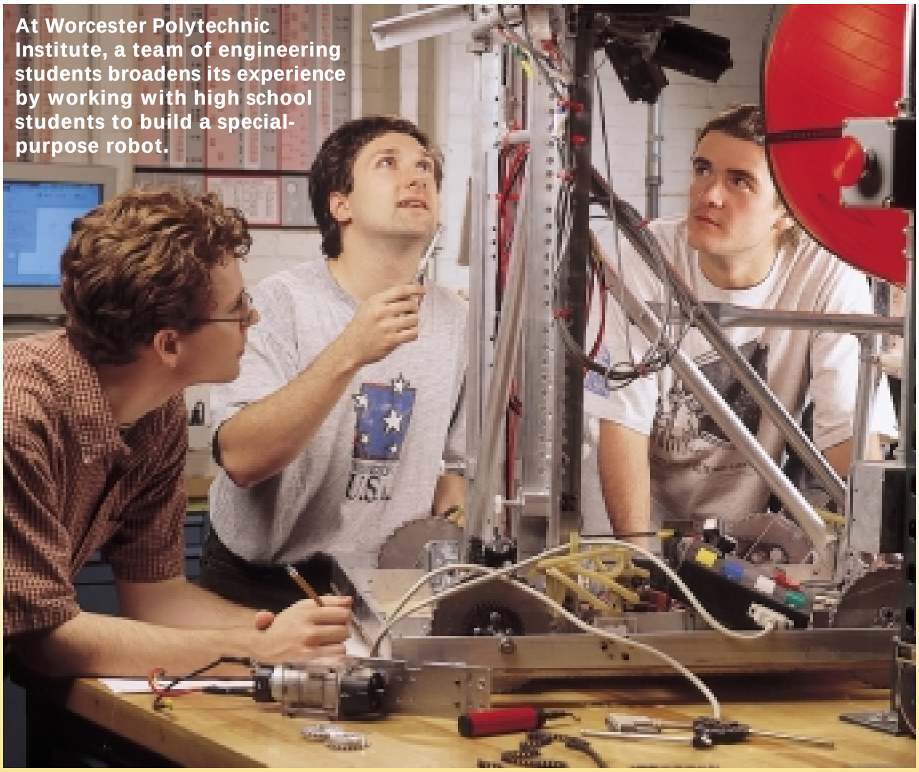

At Worcester Polytechnic Institute, a team of engineering students broadens its experience by working with high school students to build a special-purpose robot.

PATRICK O'CONNER, WORCESTER POLYTECHNIC UNIVERSITY

education

Proven skills: the new yardstick for schools

UNDER ITS NEW RULES, THE ACCREDITATION BOARD FOR ENGINEERING AND TECHNOLOGY FOCUSES ON THE RESULTS OF AN ENGINEERING EDUCATION, RATHER THAN ON THE CURRICULUM

TRUDY E. BELL
Contributing Editor

GOOD ENGINEERS POSSESS MORE THAN TECHNICAL competence—they are also skilled in teamwork, communications, ethics, and the evaluation of engineering problems in societal and global contexts. Then, of course, so rapidly are technical fields changing that even the core of an engineering education must be constantly reevaluated. In graduates today, dedication to continued learning is probably more important than mastery of specific technical concepts.

GARY W. MEEK, GEORGIA INSTITUTE OF TECHNOLOGY

Teams of undergraduates in the robotics laboratory at the Georgia Institute of Technology write computer programs utilizing the school's XR4 (Rhino) robot. In this case, they programmed the robot to dial a telephone.

Those are some assumptions used for evaluating college and university engineering education by the revolutionary Engineering Criteria 2000 (EC 2000), issued by the Accreditation Board for Engineering and Technology (ABET). No longer will curriculum content be key. As of September 2001, when the document becomes mandatory, EC 2000 will emphasize instead the learned abilities an engineer should possess upon entering into professional practice.

With this simple, yet radical, change in focus from input to outcome, EC 2000 aims to get faculties to overhaul their teaching methods and curricula. The criteria are even sparking international educational reform. Many non-U.S. institutions want their programs awarded the status of "substantial equivalency" to U.S. programs, so their graduates can more realistically aspire to jobs anywhere in the world.

In formulating the novel criteria, ABET, a nonprofit organization, based in Baltimore, Md., did not go it alone. It had the cooperation of academia, industry, and 29 professional engineering societies, including the IEEE. ABET, or its predecessor organization, has been evaluating the quality of undergraduate and graduate engineering programs across the United States since 1932. It now accredits some 2300 engineering, engineering technology, and engineering-related educational programs at over 500 colleges and universities.

THE USUAL CRITERIA— AND HOW THEY FAILED

The significance of EC 2000 is best understood by contrasting it with ABET's previous accreditation criteria. In the 1950s, the criteria for evaluating engineering programs ran to just 1-1/4 pages. By the early '80s, some 20 pages specified particular courses in particular subjects and set the minimum number of faculty members required for a program, regardless of the program's size and mission.

So prescriptive had the criteria become that "we were counting books in the library and the number of faculty members, without regard to whether students were *learning* what they needed," said Edward Alton Parrish, president of the Worcester Polytechnic Institute (WPI), in Massachusetts, and the 1995–96 chair of ABET's Engineering Accreditation Commission.

Just as serious, the criteria made no provision for accommodating innovative project-based engineering programs that did not fit neatly into the prescribed curriculum. Educational innovators, like those at Rose-Hulman Institute of Technology, in Terre Haute, Ind., had long objected that the rigid specificity of the criteria discouraged experimentation. Indeed, by the '80s, Parrish said, the conventional criteria had become "a giant cookie-cutter stamping out homogeneous engineering programs producing homogeneous engineering graduates."

Simultaneously, a crescendo of criticism from industry warned that young engineers so stamped out were not equipped with the skills needed in the work world. All too many fledgling graduates were unpracticed at working in teams, and were inept at communicating with co-workers and managers both orally and in writing. Also, according to industry critics, they were unable to evaluating the costs of developing and manufacturing a product or to assess the impact of prospective technologies on society and the environment. The bottom line: they required too much on-the-job training before they could make useful contributions.

Matters reached a climax in 1992, when the Big 10-Plus schools—most of the largest players in engineering education—threatened to form their own group for judging engineering programs at big research universities. Worse, the specter arose of the U.S. government creating its own accreditation system.

'BREAK THE COOKIE-CUTTER'

In response to all these pressures, the ABET commission took an unprecedented step in January 1994. It met for two days to explore whether ABET's criteria for engineering programs should be modified.

That meeting recorded a historic vote. "The unanimous recommendation was to take a revolutionary, not evolutionary, approach—to start over completely with a clean sheet," Parrish recalled. "The idea was to break the cookie-cutter." A criteria committee was set up by the commission under the chairmanship of Ira D. Jacobson, 1998–99 chair of ABET's Engineering Accreditation Commission and executive vice president for academics at Embry-Riddle Aeronautical University, Daytona Beach, Fla. It drew up a draft, which many contributors edited during the commission's summer meetings in 1995 and 1996.

The result was EC 2000. The new criteria were pilot-tested at assorted educational institutions, two in 1996–97 and three more in 1997–98. With the academic year starting September 2001, EC 2000 will become the sole set of criteria for judging all U.S. engineering programs.

EC 2000 requires engineering schools to be committed to four principles that challenge long-cherished assumptions:

- Setting educational objectives is key to successful educational programs.
- Outcome assessment is essential for evaluating how well the objectives are being met.
- So-called soft (nontechnical) skills should not be neglected.
- Continuous improvement is necessary for both the schools and their graduates.

Educational objectives are to a school what strategic objectives are to businesses and military operations. Basic though the concept seems, many colleges and universities find it novel. Its purpose, in part, is to woo schools away from a practice all too common under the conventional criteria: to try to ascertain ABET's preferences and then to design an engineering program around those preferences.

Inherent in the idea of specific strategic objectives is the recognition that programs in different schools might have quite different missions (for example, educating future researchers and educators versus training bench engineers for local manufacturers). "EC

2000 encourages institutions to individualize their programs based on goals and constituencies," explained Dan Hodge, ABET's accreditation director. "You tell us what your objectives are, and what outcomes you expect in the context of your objectives, and we'll do the evaluation in that context."

Outcomes assessment turns the classical view of a curriculum upside down. In the past, professors thought of academic courses (such as circuit theory, differential equations, electromagnetic theory, and quantum mechanics) as the foundation, surmounted by a capstone design experience in the senior year.

"But in that classical structure, there is no guarantee that a student actually learned all the essentials," explained William Durgin, K.G. Merriam Professor and associate provost for academic affairs at Worcester Polytech. Often individual professors designed their courses in isolation from their colleagues, so material might be repeated or omitted. Thus, students could pass an exam, and a course, and eventually a whole program without being exposed to such basics as how to apply differential equations to an engineering problem. In short, "passing exams, or even whole courses, does not necessarily reflect that essential learning took place," Durgin pointed out.

To rectify that weakness, EC 2000 encourages schools to do two things. First, they must structure each course so that anyone passing it has achieved specified outcomes [see "ABET's new accreditation criteria," p. 66]. Second, the self-study report that a school prepares under EC 2000 before an ABET accreditation visit must be structured to encourage deans and faculty to examine a curriculum as a total program.

HOW'RE WE DOING?

Expanding on outcome assessments, Durgin said, "Each course needs its own objective statement, and some way of determining whether the student achieved the objective." Letter grades may be supplemented by student portfolios of design work, akin to those that architecture students have been required to compile for many decades.

Also, professors must be willing to face some tough questions, Durgin noted, such as: "Are they prepared not to pass students who have not achieved the outcomes?"

As for the entire program's strategic objectives, each course has to contribute to their attainment and its content has to be tightly integrated with the content in the rest of the curriculum. Moreover, the program's objectives must be closely tied to the outcomes specified by EC 2000.

GETTING TOUGH ABOUT SOFT SKILLS

The third new educational principle is that nontechnical as well as technical skills are essential. After all, industry's message is that technical attributes alone do not make a good engineer. According to the EC 2000 outcomes, graduates must prove competent in practical issues. Specifically, students must show they can function on multidisciplinary teams, communicate effectively, understand professional and ethical responsibility, and conceive of the impact of engineering issues on society and the outside world.

One implication for faculty members is cautionary. "Advisors of projects need to be vigilant, and make sure that students [in team projects] function as a genuine team, not just carve up the projects into separate modules that they do individually and then assemble the day before the project is due," Durgin pointed out.

Graduates must also commit to life-long learning. "It's impossible to cram everything a student needs to know into a four- or five-year—or even into a 10-year—degree program," observed Boeing Technical Fellow John McMasters, of the Boeing Co., Seattle, Wash., a long-time activist for engineering education reform. "Therefore, you want to give students the proper foundation and the drive for lifelong learning."

"The single most important thing is to develop students' attitude to [being] inquisitive engineering professionals," agreed ABET's executive director George Peterson. "Instilling that attitude is more important than instilling technical content—because technical content changes. Now that's blasphemy, isn't it?"

EVERY DAY, IN EVERY WAY...

Continuous improvement applies to the learning institutions as well. Each engineering program must ascertain how students are measuring up, and those measures must be fed back to faculty so that instruction can be improved. In other words, deans and professors must write their program and course objectives in terms definite enough for students' performance to be measured against them. The requirement also means that a program must tie its objectives closely to the outcomes specified in EC 2000.

Continuous improvement is a sweeping culture change in colleges and universities. Historically, higher education has given no structured encouragement to a search for better teaching methodologies, noted ABET's accreditation director Hodge. "Most faculty learn to be professors from their own previous professors—but do faculty need to teach one way simply because they've always taught that way?" Hodge asked. "Does every course have to be in lecture mode? Could some elements be better delivered by other methods?" Examples might include several professors team-teaching courses involving ethics and communications as well as engineering principles, student team projects in real field work, and creative use of the Internet.

Most importantly, continuous improvement must be carried on, well, continuously—not once every six years, just before ABET comes to town. Under EC 2000, the process of gathering data on student performance, examining outcomes against a program's educational objectives, and feeding back the results to departments and faculty must be an annual—if not a daily—activity. Remarked WPI's Parrish, "With EC 2000, you have to work on outcomes assessment and improvement [absolutely] all the time or you're in deep sand."

LEADING CHANGE FROM WITHIN

Neither EC 2000 nor any other set of criteria will yield meaningful and enduring change unless individual faculty members at a given institution buy into it and make it part of the culture, according to M. Dayne Aldridge, now dean of the School of Engi-


ROSE-HULMAN

The three-year-old Center for Technological Research with Industry at Rose-Hulman Institute of Technology houses 25 labs where undergraduates and faculty work on real industrial projects.

neering at Mercer University, Macon, Ga. As chair of ABET's Engineering Accreditation Commission 1997–98, he personally carried that message to ABET.

Specifically, Aldridge pointed out, faculty would need more first-hand knowledge of professional practice in industry. They need to model teamwork by team-teaching as well as by guiding student teams. They must coordinate the content and pedagogy of their own courses with those of their colleagues to ensure that students achieve the program's overall outcomes. And they have to refine individual courses and the curriculum as a whole based on what they learn through regular student and employer assessments.

But there was a big problem. ABET itself and its entire way of conducting accreditation visits conjured up a negative image in academia. By the early '90s, "ABET was often perceived to be the enemy, like the IRS [U.S. Internal Revenue Service] conducting audits," recalled Richard A. Kenyon, 1993–94 chair of the accreditation commission and currently dean emeritus of the Kate Gleason College of Engineering at Rochester Institute of Technology, in New York. Because of the resulting distrust, the board had an uphill battle getting across the fact it was not visiting campuses to close programs down.

To deal with that negative image, the accreditation board started working collaboratively with programs well in advance of a visit. With the five schools that volunteered to be pilots for testing EC 2000 in 1996 and 1997, "we went to great lengths so that the teams of evaluators and the deans would develop collegial relations," recalled ABET executive director Peterson. "For example, we asked them, 'Here are the outcomes and attributes of an engineer specified in EC 2000. How do *you* think you could provide good evidence of measuring and achieving them?' Then we had a dialog for three to four months until we agreed on what would be submitted as acceptable evidence. And we continued the dialog into the visit so we avoided the surprise of showing up on campus and saying 'Oh, you missed the point.' "

ABET's new accreditation criteria

In September 2001 (the academic year 2001–02), Engineering Criteria 2000 (EC 2000) will become mandatory for the accreditation of all U.S. undergraduate and graduate engineering programs. Until then, engineering programs may elect to be accredited under either EC-2000 or the much lengthier and more prescriptive conventional criteria.

The conventional criteria—as well as the full text of EC 2000 and its requirements for specific engineering disciplines (electrical, mechanical, civil, and so on) and other information about the accreditation process—can be found on the Web site of the Accreditation Board for Engineering and Technology (ABET) Inc. at http://www.abet.org.

The verbatim text of three of the eight new EC 2000 general criteria for accrediting U.S. college and university engineering programs follows. These three criteria form the heart of the revolutionary new standards.

Criterion 2.
Program Educational Objectives

Each engineering program for which an institution seeks accreditation or re-accreditation must have in place:

(a) detailed published educational objectives that are consistent with the mission of the institution and these criteria

(b) a process based on the needs of the program's various constituencies in which the objectives are determined and periodically evaluated

(c) a curriculum and processes that ensure the achievement of these objectives

(d) a system of ongoing evaluation that demonstrates achievement of these objectives and uses the results to improve the effectiveness of the program.

Criterion 3.
Program Outcomes and Assessment

Engineering programs must demonstrate that their graduates have:

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs

(d) an ability to function on multi-disciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Each program must have an assessment process with documented results. Evidence must be given that the results are applied to the further development and improvement of the program. The assessment process must demonstrate that the outcomes important to the mission of the institution and the objectives of the program, including those listed above, are being measured. Evidence that may be used includes, but is not limited to the following: student portfolios, including design projects; nationally-normed subject content examinations; alumni surveys that document professional accomplishments and career development activities; employer surveys; and placement data of graduates.

Criterion 4.
Professional Component

The professional component requirements specify subject areas appropriate to engineering but do not prescribe specific courses. The engineering faculty must assure that the program curriculum devotes adequate attention and time to each component, consistent with the objectives of the program and institution. Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political. The professional component must include

(a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline

(b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study

(c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives.

—T.E.B.

GLOBAL IMPLICATIONS

ABET does not outright accredit non-U.S. engineering programs, apart from those at the American University campuses scattered around the world but chartered in the United States. At most, the board will evaluate a non-U.S. program to decide if it is "substantially equivalent" to accredited programs in the United States. But already, a year before EC 2000 becomes mandatory, several engineering programs in non-U.S. institutions of higher learning have asked ABET to evaluate them under EC 2000.

"ABET is generally viewed around the world as the premier body for accrediting engineering programs," explained Parrish. Thus, international schools "sometimes seem to feel better off getting substantial equivalency status from ABET than getting actual accreditation from agencies in their own countries," he said. Moreover, EC 2000's emphasis on outcomes makes estimating equivalency easier than trying to compare the content of specific courses and curricula.

ABET has signed an agreement with accreditation agencies in Australia, Canada, Hong Kong, Ireland, New Zealand, South Africa, and the United Kingdom to work toward reciprocity, whereby programs accredited by one body are recognized by the others. This agreement, called the Washington Accord, is "aimed at improving the mobility of the engineering workforce in a global economy," Parrish continued.

ABET is also helping Argentina, El Salvador, and Mexico to set up their own accreditation bodies. It is working closely, too, with Japan, which in November 1999 voted to set up almost an exact replica of EC 2000 and ABET's accreditation process. Until then, engineering programs had been authorized by Japan's Ministry of Education, but with no ongoing process of re-accreditation.

All this consorts well with a strategic plan ABET adopted in 1997, aiming to provide world leadership not only in engineering, but also in accrediting technology and applied science programs. One of the plan's goals identifies the board's goals as being to increase international accreditation activities and consulting, and to expand mutual recognition agreements.

MEASURING EC 2000'S LEVERAGE

ABET had one overarching objective for EC 2000: to make accreditation "a process by which institutions can improve themselves," to quote the board's executive director Peterson. "If ABET itself can encourage creativity by criteria and actions, then faculty will feel more comfortable in making *revolutionary* changes in their curricula."

The goal is to encourage variety in engineering programs—which will lead to competition among them, and hence to new directions for the fields and to better-qualified graduates.

So far, Peterson noted, anecdotal evidence suggests that EC 2000 is indeed having that effect. Most of the evidence exists in the form of "informal comments from individual deans saying something like 'It's refreshing—it's the first time we've looked at our engineering programs in 25 or 30 years,' " Peterson said.

Either in anticipation of, or as a result of, undergoing evaluation under EC 2000, several of the pilot schools have already acted. They have completely overhauled their engineering program curricula as well as the content of individual courses.

A radical example is to be found at Union College, a liberal arts college in Schenectady, N.Y., which moved from a lecture-based building-block engineering curriculum to a project-based curriculum. Among other changes, Union College professors devised a common freshman year for all engineering and computer sciences students, complete with an introduction to the culture, ethics, and historical elements of the engineering professions.

The changes also required all engineering students to gain international experience, such as a term in industry abroad; created integrated math and physics courses in a just-in-time format; and enabled engineering majors to pursue a liberal arts minor and liberal arts majors to pursue newly created technological minors.

Similarly, at Worcester Polytechnic Institute, beginning in the 1999–2000 academic year, the instructor of every undergraduate course was asked to develop a list of educational outcomes along with a plan for measuring each outcome.

In addition, the EE faculty has been revising the roles of mathematics and pure science in the engineering curriculum. One freshman calculus professor (John Goulet), on his own initiative—even though the math department does not fall under ABET's purview—revamped his courses beginning in the fall of 1999 to provide students with concepts that would help them in engineering courses. ◆

TO PROBE FURTHER

For the text of both the traditional and the EC-2000 criteria for accrediting engineering programs, the self-assessment questionnaire for programs, and details about equivalency for international programs, contact Accreditation Board for Engineering and Technology Inc., 111 Market Place, Baltimore, MD 21202; e-mail, accreditation@abet.org; Web, www.abet.org.

The IEEE Educational Activities Board is presently soliciting engineers to serve as program evalutators. Nominations will be accepted through 31 October 2000. More information is available (for engineering programs) on the Web site at www.ieee.org/organizations/eab/apc/ceaa/engapplication.htm, and (for engineering technology) on the site at www.ieee.org/organizations/eab/apc/ctaa/techapplication.htm.

"EC 2000: The Georgia Tech Experience," by Jack R. Lohmann (*Journal of Engineering Education,* July 1999, pp. 305–10) recounts the challenges in one pilot school's search for objectives and outcomes that can be measured.

Early work on the use of continuous improvement in engineering education was pioneered by Charles E. Wales and Robert A. Stager. The seminal articles describing their work, published in 1972 in *Engineering Education,* Vol. 62, are "The Design of an Educational System," (no. 5, February) and "Guided Design: A New Concept in Course Design and Operation," (no. 6, March). Wales later reported on the impact of this approach with freshmen on the performance of juniors and seniors in his book *The Guided Design Approach* (Educational Technology Publications, Englewood Cliffs, N.J., 1978).

Schenectady, N.J.-based Union College's overhaul of its entire engineering curriculum, inspired by EC 2000, is detailed course by course in the 100-page report "Engineering Education for the 21st Century: Union College Curricula Development Award 1993–98: Final Report to the GE Foundation."

John Goulet at Worcester Polytechnic Institute detailed his revamping of his calculus courses in fall, 1999, to support the engineering department in "An Outcomes Oriented Approach to Calculus Instruction" (internal memo). For just one example of a course, see his Web page http://www.wpi.edu/~goulet/calc4P/syll.htm.

How EC 2000, the Internet, and societal demands are affecting engineering education is discussed in Chapter 12, "Preparing Engineers for Tomorrow," in *Engineering Tomorrow: Today's Technology Experts Envision the Next Century,* by Trudy E. Bell and Dave Dooling, edited by Janie Fouke (IEEE Press, Piscataway, N.J., 2000).

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