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- The American Society for Engineering Education for access to its engineering program database, which enabled us to identify and specify the study population and develop our sampling design.
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- The members of our National Advisory Board (see Appendix C) for their sage advice and steady support.
- The deans, department chairs, faculty members, 1994 graduates, and 2004 graduates of the 40 institutions that participated in our study; without their cooperation, this project could not have happened.
- The Penn State College of Engineering faculty members and students, the ABET

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Engineering Change: A Study of the Impact of EC2000

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Are post-EC2000 engineering graduates any better prepared to enter the profession than were their pre-EC2000 counterparts of a decade ago? That question is at the heart of this three-year study, titled *Engineering Change: A Study of the Impact of EC2000*.

In 1996, the ABET Board of Directors adopted the new set of standards, called *Engineering Criteria 2000* (EC2000). EC2000 shifted the basis for accreditation from inputs, such as what is taught, to outputs — what is learned. The new criteria specify 11 learning outcomes and require programs to assess and demonstrate their students' achievement in each of those areas. EC2000 retains earlier accreditation standards' emphases on the development of students' mathematical, scientific, and technical knowledge, as well as standards for program faculty and facilities, but it also emphasizes developing other professional skills, such as solving unstructured problems, communicating effectively, and working in teams. In addition, EC2000 stresses awareness of ethical and contextual considerations in engineering.

In 2002, ABET, Inc., commissioned the Center for the Study of Higher Education at Pennsylvania State University to undertake a three-and-a-half-year study to assess whether the implementation of the new EC2000 evaluation criteria is having the intended effects. *Engineering Change: A Study of the Impact of EC2000* was designed to answer two primary questions:

- What impact, if any, has EC2000 had on student learning outcomes in ABET-accredited programs and institutions?
- What impact, if any, has EC2000 had on organizational and educational policies and practices that may have led to improved student learning outcomes?

Origins of EC2000

Since 1932, ABET, Inc., has been the recognized U.S.

To answer these questions, the Penn State research team examined educational practices in engineering programs and assessed student performance pre- and post-implementation of EC2000. The conceptual model guiding the study (see Figure 1) summarizes the logic of the study's design.

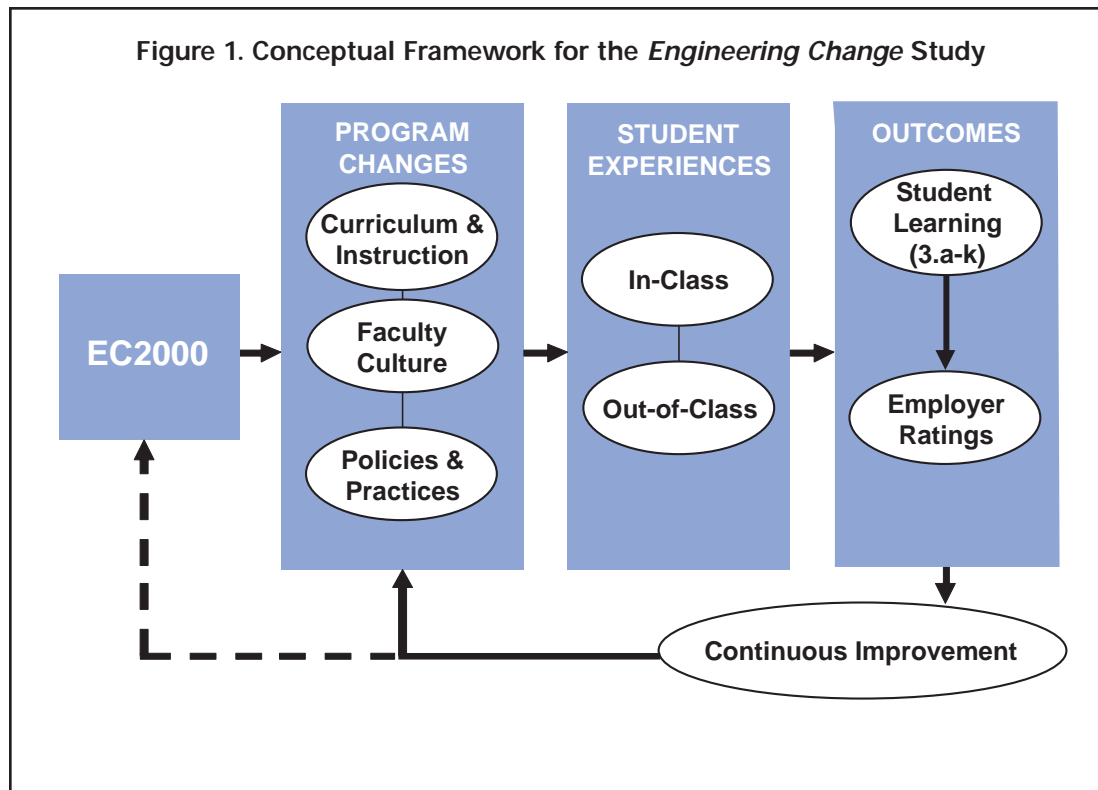


Figure 1 assumes that, if implementation of the EC2000 evaluation criteria is having the desired effect, several changes in engineering programs would be evident:

- Engineering programs would make changes to align their curricula and instructional practices with the 11 learning outcomes specified by EC2000 (Criterion 3.a-k, see Appendix D).
- Alterations in the faculty culture would be evident as faculty members engaged at a higher rate than before EC2000 in activities such as outcomes assessment and curriculum revision.
- Faculty and program administrators would adjust program practices and policies regarding faculty hiring, salary merit increases, tenure, and promotion criteria to give greater recognition to the kinds of teaching and learning required by EC2000.
- All of those program changes would reshape students' educational experiences inside and outside the classroom, which would in turn enhance student learning (defined as improved student performance on measures of the 11 EC2000 learning outcomes).

- Employers would report improvements in the knowledge and competencies of the engineering graduates they have hired since implementation of EC2000.

The EC2000 study evaluated these connections to assess whether any changes in engineering programs and improvements in student learning are a consequence of EC2000 rather than other factors.

Research Design and Sample Selection

The EC2000 study utilized a cross-sectional, pre- and post-EC2000 design that drew on multiple sources of evidence to provide a 360-degree view of the impact of the EC2000 accreditation criteria on the preparation of undergraduates for careers in engineering. Table 1 provides the sample size and response rate for each population studied. By social science standards, the response rates are quite respectable for studies of these populations, and the numbers of respondents provide more than adequate statistical power. [A summary of the study’s research design and methods appears in Appendix A.]

| Data Sources | Target Population | Number of Responses | Response Rate |
|------------------------|-------------------|---------------------|---------------|
| Programs | 203 | 147 | 72% |
| Faculty | 2,971 | 1,243 | 42% |
| Deans | 40 | 39 | 98% |
| 1994 Graduates (Pre-) | 13,054 | 5,494 | 34% |
| 2004 Graduates (Post-) | 12,921 | 4,330 | 36% |
| Employers | unknown | 1,622 | N/A |

Findings from the EC2000 Study

Major findings from the EC2000 study are reported according to the logic of the conceptual model given in Figure 1.

Changes in Engineering Programs

According to program chairs and faculty members, engineering program curricula changed considerably following implementation of the EC2000 criteria. Although few programs reduced their emphasis on the foundational topics in mathematics, basic science, and engineering science, both program chairs and faculty members report increased emphasis on nearly all of the professional skills and knowledge sets associated with EC2000 Criterion 3.a-k. Three-quarters or more of the chairs report moderate or significant increases in their program’s emphasis on communication, teamwork, use of modern engineering tools, technical writing, lifelong learning, and engineering design. Similarly, more than half of the faculty respondents report a moderate to

Key Findings: Changes in Engineering Programs

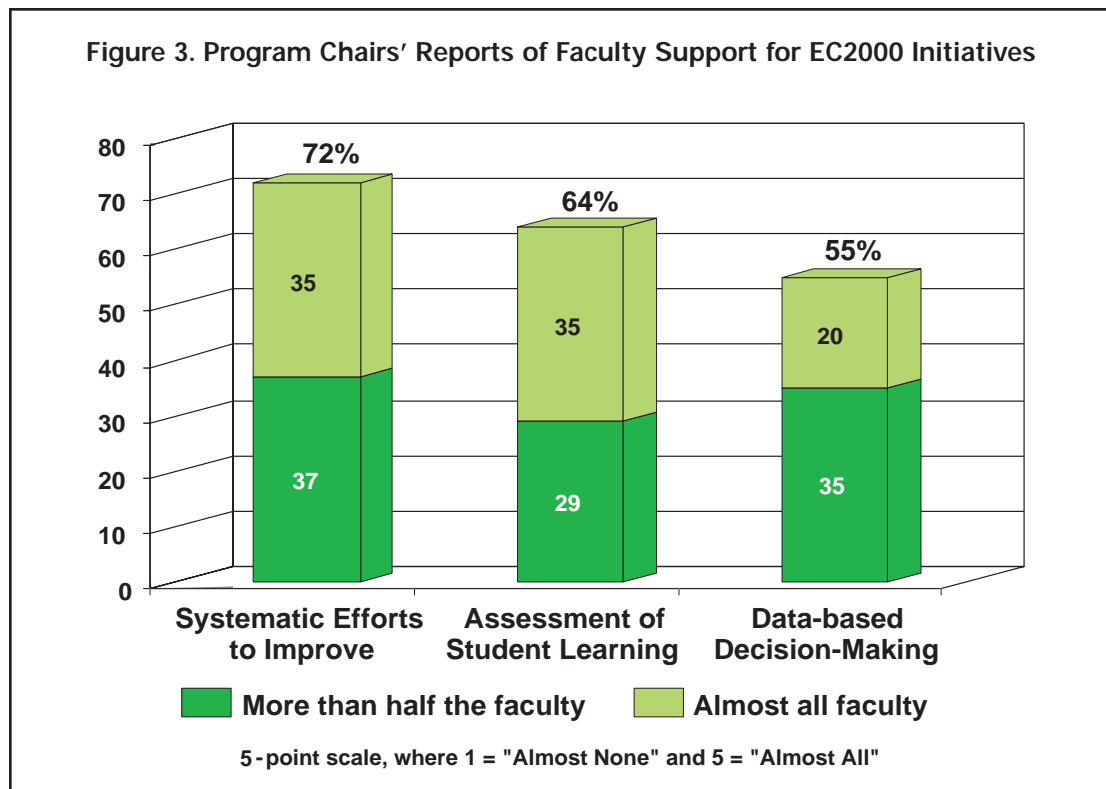
- Greater emphasis on professional skills and active learning after EC2000.
- High levels of faculty support for continuous improvement.
- Mixed emphasis on teaching in faculty reward structure.

significant increase in their emphasis on the use of modern engineering tools, teamwork, and engineering design in a course they taught regularly.

EC2000's focus on professional skills might also be expected to lead to changes in teaching methods as faculty members seek to provide students with opportunities to learn and practice their teamwork, design, and communication skills. Consistent with that expectation, half to two-thirds of the faculty report that they have increased their use of active learning methods, such as group work, design projects, case studies, and application exercises, in a course they teach regularly (See Figure 2).

Are these curricular and instructional changes attributable to EC2000 or to other influences shaping engineering education? Program chairs are much more likely than faculty to credit ABET (70% vs. 28%, respectively) and industry (78% vs. 28%) with having a moderate

of faculty support for these practices (see Figure 3). More than 75 percent of the chairs estimate that either more than half or almost all of their faculty supported continuous improvement efforts, and more than 60 percent report moderate to strong support for the assessment of student learning. Faculty corroborated this finding: Nearly 90 percent of the faculty respondents report some personal effort in assessment, and more than half report moderate to significant levels of personal effort in this area. For the most part, moreover, faculty members do not perceive their assessment efforts to be overly burdensome: Nearly 70 percent think their level of effort was “about right.”



Learning how to do assessment or incorporate active learning methods into courses may also influence faculty members' engagement in professional development opportunities focused on teaching and learning. This study finds that more than two-thirds of the faculty members report reading more about teaching in the past year, and about half engage in formal professional development activities, such as attending seminars or workshops on teaching, learning, and assessment, or participating in a project to improve engineering education. Depending on the activity, one-fifth to one-quarter of the faculty members say that in the past five years they have increased their teaching-and-learning-related professional development efforts.

One of the most important influences on faculty work in colleges and universities is the institutional reward system, which can encourage or discourage attention to teaching. The EC2000 accreditation criteria require that engineering programs be responsible for the quality of teaching, learning, and assessment, but do faculty members believe that their institutions value their contributions in these areas when making decisions about promotion, tenure, and merit-based salary increases? About half of the program chairs and faculty surveyed see no change in their institution's reward system over the past decade. About one third of the pro-

gram chairs, however, report an increase over the past decade on the emphasis given to teaching in faculty hiring, promotion, tenure, and salary and merit decisions. In contrast, roughly one-quarter of the faculty respondents believed the emphasis on teaching in their reward systems had decreased in the same time period. Senior faculty members, however, tend to report increased emphasis on teaching in promotion and tenure decisions whereas untenured faculty are more likely to report decreased emphasis.

Differences in Student Experiences

Have the program changes reported by chairs and faculty had a measurable impact on the educational experiences of engineering undergraduates? The evidence suggests they have. Indeed, the experiences of the 2004 graduates differ in a number of ways from those of their counterparts of a decade earlier. The direction of seven of the 10 differences, moreover, is consistent with what one would expect if EC2000 were putting down roots. Compared to their 1994 counterparts, and after taking differences in graduates' and institutional characteristics into account, 2004 graduates reported:

- More active engagement in their own learning;
- More interaction with instructors;
- More instructor feedback on their work;
- More time spent studying abroad;
- More international travel;
- More involvement in engineering design competitions; and
- More emphasis in their programs on openness to diverse ideas and people.

Although they tend to be small, seven of 10 statistically significant differences between pre- and post-EC2000 graduates persist even after adjusting for an array of graduate and institutional characteristics.

The exceptions are the absence of differences in instructor teaching skills and the hours spent in cooperative or internship experiences, as well as the 2004 graduates' reports of a somewhat chillier diversity climate than that cited by their predecessors. The latter finding may be related to several factors: differences in the gender and racial/ethnic mix in 1994 and 2004, graduates' awareness of diversity issues, and/or their willingness to discuss and challenge prejudice or discrimination. The evidence provides no guidance in the way of an explanation.

Differences in Learning Outcomes

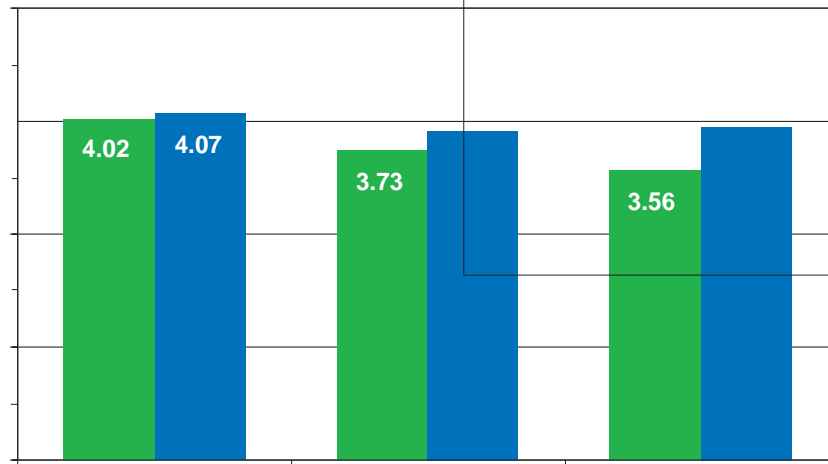
Assessments of graduates' skill levels on each of nine scales¹ reflecting EC2000 Criterion 3.a-k learning outcomes are based on graduates' self-reports of their ability levels at the time of graduation (using a five-point scale, where 1="no ability" and 5="high ability"). A growing body of research over the past 30 years has examined the adequacy of self-reported measures of learning and skill development as proxies for objective measures of the same traits or skills. When self-reports are aggregated to compare the performance of groups, they are generally considered to be valid measures of the skills under study. Although results vary depending on

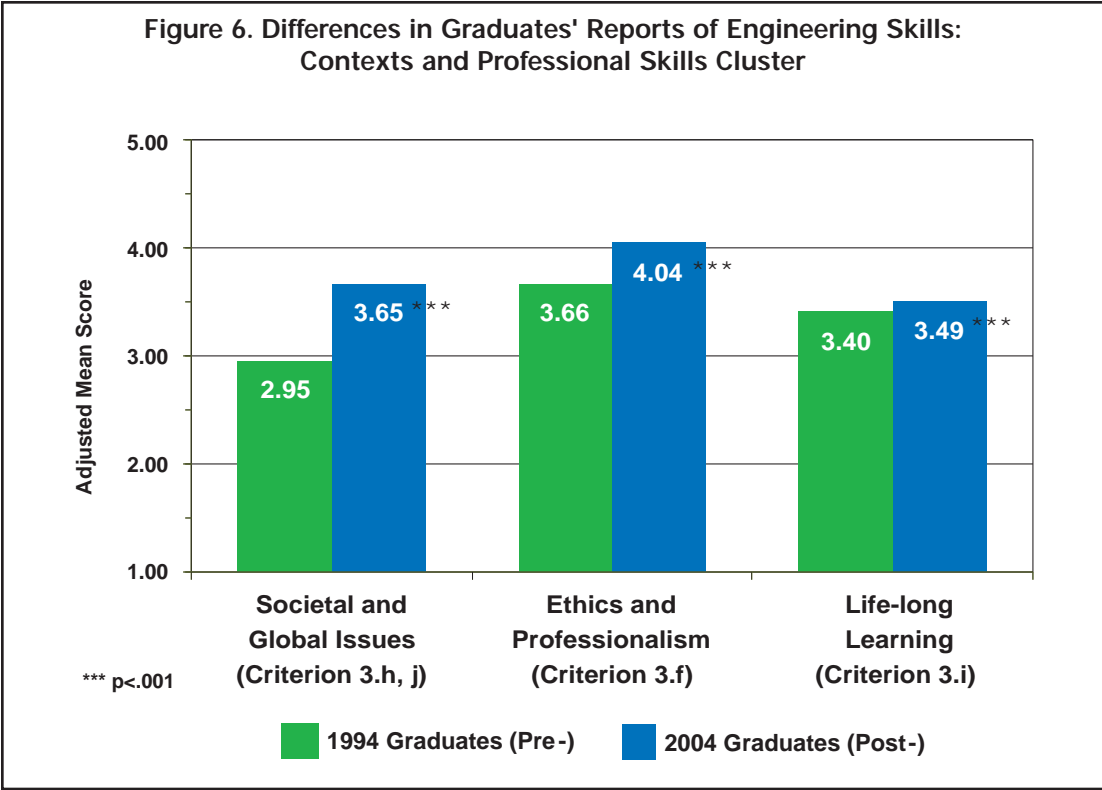
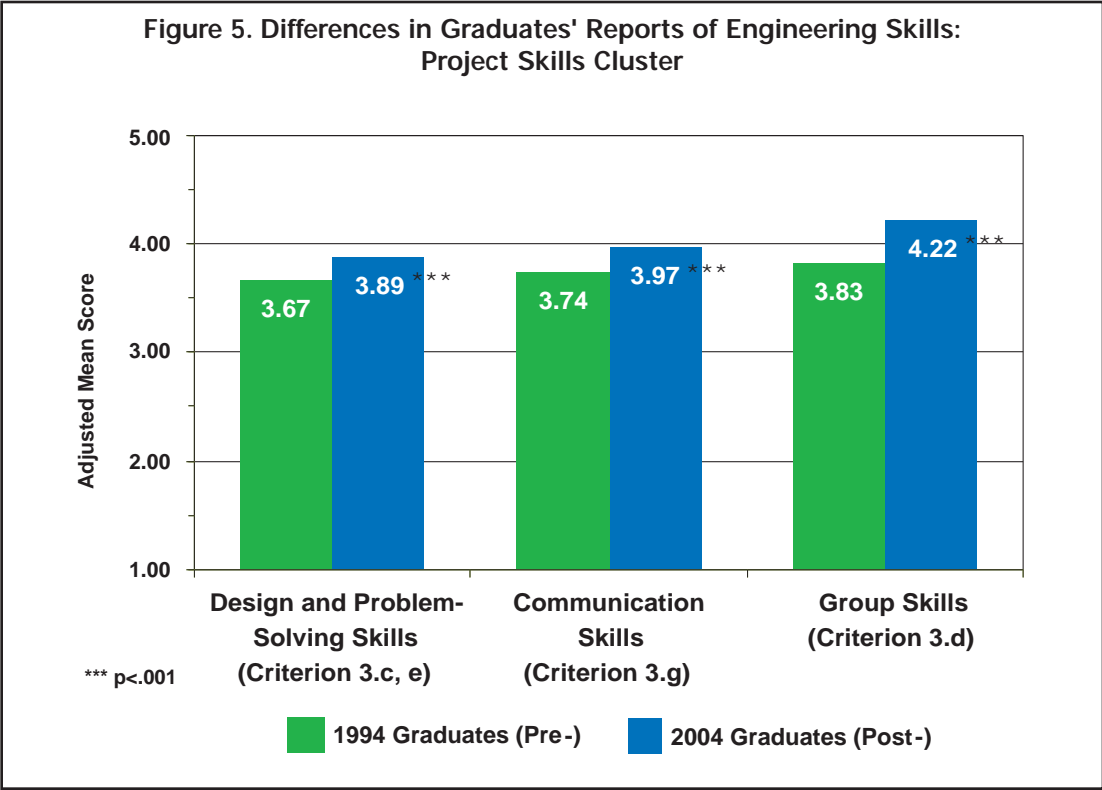
¹ In statistical analyses, two of the 11 scales developed a priori to operationalize the a-k criteria collapsed into other scales, leaving a total of nine measurement scales to reflect student learning.

the traits and instruments examined, these studies report correlations of .50 to .70, on average, between self-reports and such objective criterion measures as the ACT Comprehensive Test, the College Basic Academic Subjects Examination, and the Graduate Record Examination. The original research design called for comparison of graduates' scores on the 1996 and 2004 Fundamentals of Engineering examination as a measure of graduates' content mastery. However, the

research team was unable to obtain permission to use those scores.

Figures 4 - 6 show the differences between 1994 and 2004 graduates' reports of their achievements on each of the nine scales reflecting the Criterion 3.a-k learning outcomes. In all cases, the differences are consistent with what one would expect under the assumption that EC2000 is having an impact on student learning. All differences, moreover, are statistically significant ($p < .001$), with effect sizes ranging from +.07 to +.80 of a standard deviation (mean = +.36).² Five of the nine effect sizes exceeded .3 of a standard deviation, an effect size that might be characterized as "moderate."

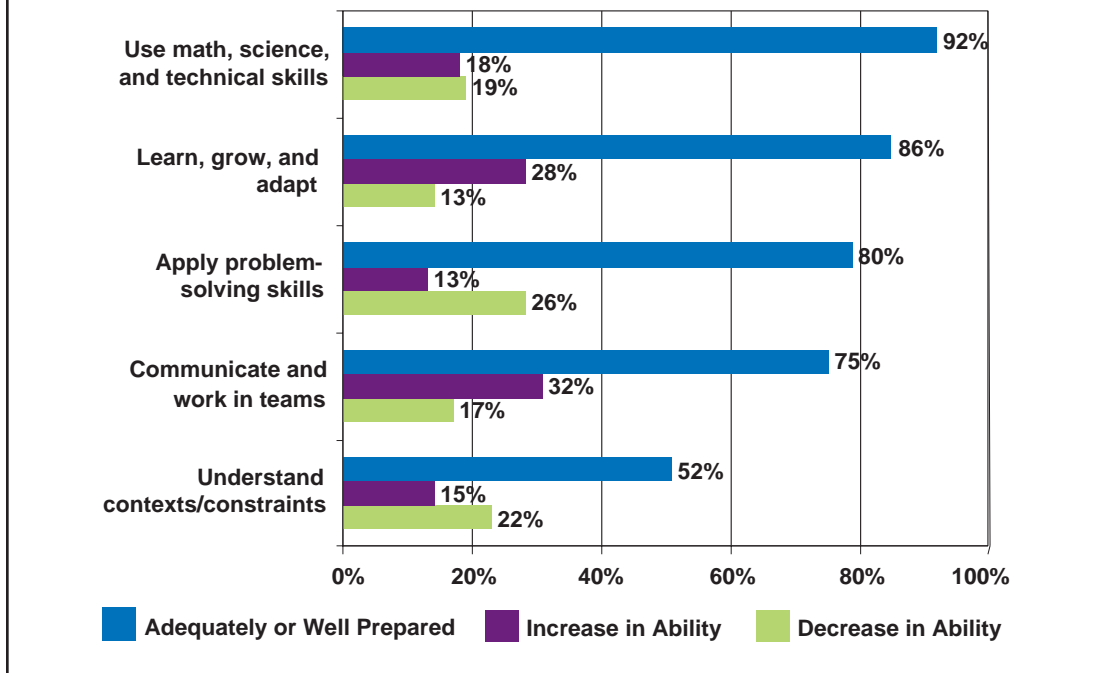




The largest differences between 1994 and 2004 graduates are in five areas: Awareness of societal and global issues that can affect (or be affected by) engineering decisions (effect size = +.80 of a standard deviation), applying engineering skills (+.47 sd), group skills (+.47 sd), and awareness of issues relating to ethics and professionalism (+.46 sd). The smallest difference is in graduates' abilities to apply mathematics and sciences (+.07 sd). Despite that small but statistically significant difference, this finding is particularly noteworthy because some

Finally, students' undergraduate program experiences, both in- and outside-the-classroom, are clearly linked to what and how much students learn. Nine of 10 measures of their in- and out-of-class experiences have statistically significant, positive, and sometimes substantial influences on graduates' reports of their ability levels on all nine of EC2000's a-k learning outcome measures. The clarity of the instruction received, the amount of interaction with and feedback from instructors, and exposure to active and collaborative learning experiences are consistently the most powerful influences on learning of any factors in the study, all having a positive influence on learning. Out-of-class experiences, however, also shape student learning. Important out-of-class experiences include internships or cooperative education experiences, participation in design competitions, and active participation in a student chapter of a professional society or association. These experiences significantly and positively affect learn-

Figure 9. Employers' Reports of Engineer Preparation and Changes in Ability



declined modestly, although eight out of 10 employers judge the problem-solving skills of their new hires to be at least adequate. In contrast, barely half of the employers give an adequate rating to new graduates' understanding of the organizational, cultural, and environmental contexts and constraints of their work. Additionally, graduates' skills in this area, according to their employers, appear to have declined somewhat over the past decade.

Despite their heterogeneity, employers are in substantial agreement not only about the importance of a-k, but also about the preparation of new engineers, regardless of their engineering discipline. An extensive series of tests indicated only a handful of significant differences related to employers' engineering field, industry sector, degree attainment, or geographic location. Analyses indicate, however, that employers from larger companies that recruit nationally and hire the most engineers are more favorable in their judgments both of new engineers' preparation and of the pre-post-EC2000 change than are employers from smaller companies that recruit locally and hire fewer employees. This finding may suggest that the impact of EC2000 is just beginning to become visible to employers, and the larger national companies may be seeing the changes first.

Conclusions

The weight of the accumulated evidence collected for *Engineering Change* indicates clearly that the implementation of the EC2000 accreditation criteria has had a positive, and sometimes substantial, impact on engineering programs, student experiences, and student learning. Comparisons of 1994 and 2004 graduates' self-reported learning outcomes show 2004 graduates as measurably better prepared than their counterparts in all nine learning areas assessed. The greatest differences in student learning before and after EC2000 are in recent

graduates' better understanding of societal and global issues, their ability to apply engineering skills, group skills, and understanding of ethics and professional issues.

Engineering Change assumed that if the new EC2000 accreditation criteria were having an impact, engineering programs would be moving to align their curricula and instructional methods with the goals of the new criteria, thus increasing student engagement in experiences that would promote the learning outcomes specified in the criteria. The findings from this study strongly suggest that improvements in student learning have indeed resulted from changes in engineering program curricula, teaching methods, faculty practices, and student experiences inside and outside the classroom. Although many dimensions of engineering programs shape learning, the findings of this study indicate that students' classroom experiences are the most powerful and consistent influences. Engineering programs and faculty can be confident that their efforts to improve engineering courses and programs will benefit students and the profession.

In the spirit of continuous improvement, ABET made a decision in 2002 to sponsor this study. The completion of the *Engineering Change* project establishes a baseline for the preparation of engineers and provides a model for future assessments of the state of undergraduate engineering education and student learning. As the first national study of an outcomes-based accreditation model, this research also informs ongoing discussions of accreditation policy among regional and professional accreditation agencies, state and federal legislators, and the general public – all of whom want evidence of the rigor of higher education quality assurance practices.

Appendix A: Study Design and Methods

Research Design and Data Collection

The *Engineering Change*

Appendix B: *Engineering Change* Study Team

Center for the Study of Higher Education, The Pennsylvania State University

- Dr. Lisa R. Lattuca, Project Director and Co-Principal Investigator
- Dr. Patrick T. Terenzini, Co-Principal Investigator
- Dr. J. Fredericks Volkwein, Co-Principal Investigator
- Dr. Linda C. Strauss, Senior Project Associate
- Graduate Research Assistants: Vicki L. Baker, Robert J. Domingo, Betty J. Harper, Amber D. Lambert, Javzan Sukhbaatar
- Suzanne S. Bienert, Staff Assistant

The Pennsylvania State University's Center for the Study of Higher Education (CSHE) is one of the nation's first research centers established specifically to study postsecondary education issues. For over 30 years, research teams composed of nationally recognized faculty, highly qualified graduate students, and experienced professional staff have examined critical issues that influence the policies and practices of postsecondary institutions. To that end, CSHE is dedicated to conducting and disseminating theory-based empirical research designed to improve higher education practice and policy; providing high-quality data and analysis to institutional, state, and federal policy-makers; and supporting graduate training for students in the Higher Education Program at Penn State.

Persons with questions or wishing additional information are invited to contact Dr. Lisa R. Lattuca, Project Director (lattuca@psu.edu).

Appendix C: *Engineering Change* National Advisory Board

Dr. Denice Dee Denton
Chancellor
University of California-Santa Cruz

Dr. Norman L. Fortenberry
Director, Center for the Advancement of
Scholarship on Engineering Education
National Academy of Engineering

Dr. Daniel B. Hodge (ex officio)
Accreditation Director
ABET

Dr. William E. Kelly
Professor of Civil Engineering and former
Dean of the School of Engineering
Catholic University of America

Dr. David Mahan
Former Superintendent of Schools
St. Louis, Missouri

Dr. Susan B. Millar
Senior Scientist, Wisconsin Center for
Education Research (WCER)
University of Wisconsin-Madison

Dr. Eleanor W. Nault
Director, Office of Assessment
Clemson University

Dr. Barbara M. Olds
Division Director, Directorate for Education

Appendix D: *Engineering Criteria 2000*

The following is an excerpt from the *Criteria for Accrediting Engineering Programs* that were effective during the 2001-2002 ABET accreditation cycle.

Engineering Change focused on Criterion 3.a-k.

I. GENERAL CRITERIA FOR BASIC LEVEL PROGRAMS

It is the responsibility of the institution seeking accreditation of an engineering program to demonstrate clearly that the program meets the following criteria.

Criterion 1. Students

The quality and performance of the students and graduates are important considerations in the evaluation of an engineering program. The institution must evaluate, advise, and monitor students to determine its success in meeting program objectives.

The institution must have and enforce policies for the acceptance of transfer students and for the validation of courses taken for credit elsewhere. The institution must also have and enforce procedures to assure that all students meet all program requirements.

Criterion 2. Program Educational Objectives

Each engineering program for which an institution seeks accreditation or reaccreditation 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.

Criterion 5. Faculty

The faculty is the heart of any educational program. The faculty must be of sufficient number; and must have the competencies to cover all of the curricular areas of the program. There must be sufficient faculty to accommodate adequate levels of student-faculty interaction, student advising and counseling, university service activities, professional development, and interactions with industrial and professional practitioners, as well as employers of students.

The faculty must have sufficient qualifications and must ensure the proper guidance of the program and its evaluation and development. The overall competence of the faculty may be judged by such factors as education, diversity of backgrounds, engineering experience, teach-

ing experience, ability to communicate, enthusiasm for developing more effective programs, level of scholarship, participation in professional societies, and registration as Professional Engineers.

Criterion 6. Facilities

Classrooms, laboratories, and associated equipment must be adequate to accomplish the program objectives and provide an atmosphere conducive to learning. Appropriate facilities must be available to foster faculty-student interaction and to create a climate that encourages professional development and professional activities. Programs must provide opportunities for students to learn the use of modern engineering tools. Computing and information infrastructures must be in place to support the scholarly activities of the students and faculty and the educational objectives of the institution.

Criterion 7. Institutional Support and Financial Resources

Institutional support, financial resources, and constructive leadership must be adequate to assure the quality and continuity of the engineering program. Resources must be sufficient to attract, retain, and provide for the continued professional development of a well-qualified faculty. Resources also must be sufficient to acquire, maintain, and operate facilities and equipment appropriate for the engineering program. In addition, support personnel and institutional services must be adequate to meet program needs.

Criterion 8. Program Criteria

Each program must satisfy applicable Program Criteria (if any). Program Criteria provide the specificity needed for interpretation of the basic level criteria as applicable to a given discipline. Requirements stipulated in the Program Criteria are limited to the areas of curricular topics and faculty qualifications. If a program, by virtue of its title, becomes subject to two or more sets of Program Criteria, then that program must satisfy each set of Program Criteria; however, overlapping requirements need to be satisfied only once.

