Engineering Education in 2015 (or Sooner)

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Abstract

An outcomes-based accreditation system for engineering programs was adopted in 2001 in the United States and is used by all full and provisional signatories of the Washington Accord. The system requires major transformations in the ways engineering curricula are structured, delivered, and assessed. As might be expected, many engineering staff members are less than enthusiastic about the proposed changes, arguing that the existing system has always functioned well and needs no radical revision. The ongoing debate involves four focal issues: (1) How should engineering curricula be structured? (2) How should engineering courses be taught and assessed? (3) Who should teach? (4) How should the teachers be prepared? This paper outlines the opposing positions on each of these issues—the traditional position, which has been the predominant approach in engineering education for the past five decades, and the alternative position, which is far more compatible with the requirements of the Washington Accord.

Keywords: Engineering education, outcomes-based education, ABET, Washington Accord

1. Introduction

Engineering education in the United States has for many decades been heavily influenced by the Accreditation Board for Engineering and Technology (ABET), which sets and monitors standards for American engineering and engineering technology degree programs. In 1989, six nations (Australia, Canada, Ireland, New Zealand, the United Kingdom, and the United States) signed the Washington Accord, a multinational agreement that recognizes the substantial equivalency of those countries' accreditation systems, the engineering programs they accredit, and the fitness of the graduates of those programs to practice engineering at the entry level. (Engineering technology programs were dealt with in a separate agreement known as the Sydney Accord.) The full signatories were joined by Hong Kong in 1995 and South Africa in 1999.

Other nations have attained provisional signatory status in the Washington Accord by being nominated by two full signatory nations, submitting evidence that their accreditation procedures are comparable to those of the existing signatories, and being approved by two-thirds of the existing signatories. A probationary period of at least two years is specified when provisional status is granted, after which a unanimous vote of the full signatories is required for transition to signatory status. Malaysia was nominated for provisional status by Australia and the United Kingdom, and was granted that status in 2003 along with Germany and Singapore [1].

Starting in the 1970s, industry began to complain about the inadequacy of important skills (e.g., critical and creative thinking, communication, and teamwork) in new engineering graduates, and government commission reports supported those complaints. At the same time, brain research and empirical studies of teaching and learning provided increasingly strong evidence that the traditional lecture-based method of education was ineffective at facilitating development of those skills. Spurred by those growing pressures, in 1997 ABET adopted a new set of outcomes-based program evaluation criteria. The best known of these criteria (Criterion 3) listed 11 attributes that graduates of accredited engineering programs should possess. A modified version of the prescribed ABET outcomes has been adopted by signatories of the Washington Accord as part of their evaluation criteria. Those outcomes are shown in Table 1.

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The new evaluation criteria pose serious challenges for all programs pursuing accreditation under ABET and the Washington Accord. The effectiveness of the traditional lecture-based instructional approach at equipping students with factual knowledge and conventional problem-solving skills is arguable, but that approach is clearly inadequate when it comes to developing such attributes as communication skills, ethical awareness, and understanding the impact of engineering solutions on a societal and global level. To promote and assess the acquisition of such attributes requires alternative approaches to course planning, delivery of instruction, and assessment of learning outcomes. Several nontraditional teaching methods have been shown to lead to superior outcomes relative to traditional instruction, and there are growing calls to adopt them in engineering [2]. A small number of engineering curricula and a substantial number of individual instructors have already done so.

Table 1. Outcomes Specified by the Washington Accord

Programs must demonstrate that their graduates can:
• Apply mathematics, science and engineering science for the design, operation and improvement of systems, processes and machines; Formulate and solve complex engineering problems;
• Understand and resolve the environmental, economic, societal implications of engineering work;
• Communicate effectively;
• Engage in lifelong learning and professional development;
• Act in accordance with the ethical principles of the engineering profession;
• Function in contemporary society.

As might be expected, many staff members and administrators are less than enthusiastic about the proposed changes in teaching methods, arguing that the existing system functions well and needs no radical revision. The ongoing debate involves four focal issues:

1. How should engineering curricula be structures?
2. How should engineering courses be taught and assessed?
3. Who should teach?
4. How should the teachers be prepared?

This talk outlines the opposing positions on each of these issues—the traditional position (**T**), which has been the predominant approach in engineering during the past five decades, and the alternative position (**A**), which I believe must be adopted if the outcomes specified by ABET and the Washington Accord are to be satisfied. Reference [2] provides details on the alternative methods and cites numerous sources of information about them, and additional information can be found in the annotated bibliography that ends this paper.

2. How should curricula be structured?

T: *Begin with fundamentals (basic science and mathematics), then transition to engineering science, and end with engineering laboratory courses and the capstone design course.*

A: *Introduce engineering problems and projects beginning in the first year, and teach mathematical and scientific principles and methods as they are needed to solve the problems and complete the projects.*

A widely accepted principle of learning theory is that people learn more and retain longer information that they clearly perceive a need to know. The traditional curriculum presents information for two years or more with no more motivation than "Trust me—in two (or three or five) years you'll see why this material is important." Students imagine that what they are seeing resembles what they would be likely to do as engineers, which of course it does not. A result is the high rate of attrition from engineering curricula in the first year, with both weak students and good students dropping out.

T: *Curricula and courses emphasize content (facts, formulas, algorithms).*

A: *Curricula and courses balance traditional content with such skills as critical and creative thinking, problem solving, problem formulation, communication, and teamwork, and with instruction that increases professional and ethical awareness.*

One approach is to put some or all nontraditional topics in separate courses (e.g., "Introduction to Ethics" or perhaps "Ethics for Engineers"). A more effective approach is to integrate those topics into core engineering courses, where the students tend to take them much more seriously.

T: *Courses compartmentalized, self-contained, taught by individual instructor.*

A: *Courses integrated across subjects and disciplines, team-taught.*

Every instructor has had the experience of asking students questions about material from another course—perhaps one that was prerequisite to the current one, or one that the students might be taking in the same semester. Many (or most) students are likely to deny knowing anything about that material, because they are never explicitly shown the connections between different courses and disciplines and they fail to see the connections themselves. In engineering practice, problems that fall within the domain of a single subject are quite rare. The alternative approach brings out the multidisciplinary nature of real engineering problems and gives students practice in solving such problems.

T: *Single-discipline design projects done in senior capstone course.*
A: *Multidisciplinary design projects done throughout the curriculum.*

Engineering design is a complex process that involves a large variety of skills extending over a number of disciplines, not all of which are normally considered part of the engineering curriculum. It is unrealistic to expect students to acquire all of these skills in the course of completing a single project in the last semester of the engineering curriculum. Better results are obtained by starting students on design in their first year, and then continuing to give them design problems that encompass a progressively broad range of disciplines, with less and less guidance being provided as the students proceed through the curriculum. By the time they get to the capstone design course, most students with that sort of background are far more accomplished at design than they could possibly be when the traditional approach is used.

3. How should courses be taught?

T: *Content determined by syllabus.*
A: *Content determined by learning objectives.*

The traditional syllabus is a statement of the topics to be taught in a course, while learning objectives are statements of things the students should be able to *do* (explain, calculate, estimate, derive, model, design, evaluate, critique, justify,...) if they have learned the course material. Writing learning objectives for a course can dramatically transform both the course content and the way the course is taught and assessed. Sharing the learning objectives with the students before the assessments can have an equally dramatic effect on the quality of their learning.

Learning objectives serve several important purposes. They clearly define the scope and content of the course for the students, instructors of subsequent courses in the curriculum, and instructors preparing to teach the course for the first time. They also demonstrate how the course contributes to satisfying the program outcomes specified in the accreditation criteria. For this reason, a collection of learning objectives for each course in the core engineering curriculum constitutes an important part of the self-study package prepared by a program in preparation for an accreditation site visit.

T: *Deductively: Principles → formulas and algorithms → applications to problem solving.*
A: *Inductively: Principles, formulas, and algorithms are taught or discovered by students in the context of answering questions, solving authentic engineering problems, or completing engineering projects.*

Variations of the inductive approach are becoming increasingly common in engineering, including *inquiry-based learning* (questions provide the context for learning), *problem-based learning* (complex authentic open-ended problems provide the context), and *project-based learning* (projects provide the context). Reference [2] cites research showing that these techniques are equivalent to traditional lecturing at equipping students with factual knowledge and superior to lecturing at helping them develop higher-order thinking and problem-solving skills, and the same reference demonstrates that problem-based learning can be used to help students attain all 11 specified ABET Engineering Criteria outcomes.

T: *Except in laboratories, most in-class activity is done by the instructor (lecturing, occasionally asking questions).*
A: *In all courses, the burden of activity is shared by instructor and students (discussing, explaining, brainstorming, questioning, reflecting, computing...).*

Another fundamental principle of learning theory is that people learn by doing things, getting corrective feedback on their efforts, then doing them again and getting more feedback, etc. They do *not* learn in meaningful ways by watching and listening to someone else tell them what they are supposed to know. The teaching approach that puts students to work on course-related activities during class as well as outside class is known as *active learning.*

T: *Homework and tests involve convergent (single-answer) problems.*
A: *Homework and tests involve convergent problems, open-ended problems, troubleshooting, explaining observed phenomena and complex concepts, and formulating problems.*

Engineers rarely have to solve problems of the "*Given x and y, calculate z*" variety, with all the information needed to determine *z* defined and readily available. Problems like that are more likely to be solved by technicians or computers. The most difficult part of many engineering problems is often figuring out exactly what the problem is, after which the information needed to solve the problem must be identified and looked up, calculated, estimated, or measured. The problem usually does not have a unique solution but many possible solutions, each with its own advantages and disadvantages, and the engineer must decide on criteria and choose one from among all of them. If that is what professional engineers do, it follows that engineering school should teach them to do it, which can only be done by assigning such problems and providing guidance on how to solve them.

T: *Assignments are completed individually, except possibly in laboratory courses and the capstone design course.*

A: *Some assignments in lecture courses are done individually, and others are done by students working in teams with measures taken to assure individual accountability for all the learning that occurs.*

Cooperative learning is an instructional approach that involves students working in teams under conditions that assure individual accountability and help students develop teamwork and communication skills. A rich body of literature offers guidance in implementing cooperative learning and summarizes evidence that it facilitates attainment of a wide variety of learning outcomes, including all of the outcomes specified in ABET Criterion 3 [2].

T: *Teaching evaluation based entirely on student ratings.*

A: *Teaching evaluation based on student ratings, peer ratings, self-ratings, and what students learn.*

Student ratings have a great deal of validity, but there are some aspects of teaching that students are in no position to evaluate, such as whether the course content is up-to-date and provides the background needed for subsequent courses in the curriculum. The modern approach to evaluation of teaching is to use multiple sources of information (“triangulation”). The composite picture that emerges provides a much better measure of teaching quality than could be provided by any individual source of data.

T: *Courses taught by professors lecturing in classrooms and auditoriums on campuses.*

A1: *Courses taught by professors somewhere else lecturing on monitor screens.*

A2: *Courses taught using interactive multimedia tutorials and other interactive tools.*

Technology is a two-edged sword: it can greatly facilitate learning or it can act as a barrier to learning, depending on what it is and how it is used. The guiding principle is again that students learn actively, through repeated practice and feedback. To the extent that technology promotes activity, it facilitates learning; to the extent that it puts students in a passive role, it hinders learning. Relative to traditional lecturing, Alternative A2 facilitates learning and alternative A1 hinders it.

4. Who should teach?

T: *Ph.D.’s specializing in frontier disciplinary research.*

A: *Individuals specializing in diverse forms of scholarship: Discovery (frontier research), integration (applied research), application (research applied to problems of society), and teaching (pedagogy, professional practice).*

In *Scholarship Reconsidered*, Ernest Boyer [3] observed that all four of those forms of scholarship are vitally important functions of research universities, and yet only the first one is generally rewarded. His point was not that every staff member should be an expert in all four (which would be a totally unrealistic expectation), but that there should be room in every university department for one or more individuals who wish to specialize in each of them. In particular, if courses are to be taught using the alternative methods described above, someone in each department should be expected to be a teaching scholar and attend educational conferences, read the education literature, develop or import and adapt new teaching methods, implement and assess them, and transmit them to colleagues who lack the time and inclination to spend that much time on teaching. Specialists in all four forms of scholarship should be evaluated on the basis of how well they fill their roles, and they should have equal opportunity for recognition and reward, including tenure and promotion to full professor.

5. How should teachers be prepared?

T: *No preparation.*

A: *Courses on teaching in graduate school, workshops for faculty, mentorships for new staff members and graduate students.*

College teaching is the only skilled profession that does not routinely provide training to its practitioners. The assumption is that working on a doctoral research project that someone else defines is all the background that one needs to teach effectively (as well as to plan, initiate, and manage a research program). In fact, teaching is a highly complex and skilled craft, and requiring professors to learn that craft by trial-and-error is both ineffective and inefficient. Providing teacher training to both staff members and doctoral students does not require a major investment of resources but it can pay great dividends in improving the quality of a university's instructional program.

6. Remaining questions

(a) *Can we afford to do all that?*
(b) *Can we afford not to do it?*

Some of the alternative teaching methods described above require minimal investment or no investment at all. Writing learning objectives and using active learning, for example, require small amounts of an instructor's time and no additional resources at all. Other methods, such as obtaining and installing the equipment and software needed to use technology effectively and providing instructional training to teaching staff and graduate students, do require resources. At the same time, competition for good students is intensifying, and alternatives to traditional campus-based institutions such as the British Open University are becoming increasingly adept at providing high-quality education. If campus-based engineering schools adopt the alternative methods and reward instructors who implement these methods successfully, they will almost certainly remain competitive with their peer institutions. If they insist on continuing to use more traditional methods that are known to be inferior at promoting the types of outcomes required by ABET and the Washington Accord, their ability to satisfy accreditation requirements and to maintain their enrollments in an increasingly competitive market is doubtful.

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Biographical information

RICHARD FELDER is coauthor of *Elementary Principles of Chemical Processes*, which has been used as the introductory chemical engineering text by about 90% of all chemical engineering departments in the United States and at many universities internationally, and he has authored or coauthored over 200 papers on chemical process engineering and engineering education. His honors include the ASEE Chester F. Carlson Award for Innovation in Engineering Education, the AIChE Warren K. Lewis Award for Contributions to Chemical Engineering Education, and the ASEE Chemical Engineering Division Lifetime Achievement Award for Pedagogical Scholarship.