

THE FUTURE OF ENGINEERING EDUCATION – REVISITED

The landmark series “The Future of Engineering Education,” published in 2000, is the most cited series in CEE’s history. As part of the golden anniversary celebration for the 50th volume of CEE, the anniversary committee decided to request a paper that revisited this series.

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The six-part series, “The Future of Engineering Education,” by Richard Felder, James Stice, Armando Ruggarcia, and Donald Woods,^[1-6] is the best known and most cited *CEE* series. The *CEE* publication board members and editors who picked their Top 5 articles^[7] assigned the most votes to Part 2 (Teaching Methods that Work)^[2]. Part 1 (A Vision for a New Century)^[1] was second, Part 3 (Developing Critical Skills)^[3] was tied for third, Part 4 (Learning How to Teach)^[4] was tied for sixth, and Parts 5 (Assessing Teaching Effectiveness and Educational Scholarship)^[5] and 6 (Making Reform Happen)^[6] had one vote each. The *CEE* committee that selected papers for the *CEE* Startup Collection^[8] included Parts 1, 2, 3, and 5 in the collection. The Future series covers most aspects of teaching engineering, and could easily be used to teach an extended workshop for faculty. The Future series is available free on the *CEE* home page (<<http://www.che.ufl.edu/cee/>>) in the *CEE* archives (click on “Past Issues” then on “Click here to view back issues”). The Startup Collection is also available free on the *CEE* home page.

Part 1^[1] of the series boldly makes predictions about teaching engineering during the 21st Century. Part 2^[2] of the series discusses teaching methods that lead to increased student learning, Part 3^[3] explores the development of student skills, and Part 4^[4] offers advice on learning how to teach. Part 5^[5] is a buffet of material on assessment of student learning, evaluation of teaching, and engineering education research. Finally, Part 6^[6] considers how to make reform happen. To determine how well “The Future of Engineering Education”

has withstood the test of time, we address the following four questions:

1. How accurate were the predictions?
2. Is the advice in these papers still current?
3. What advances in our understanding of teaching and learning in engineering education have occurred since the turn of the century?
4. Has reform of engineering education been successful?

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This paper is organized to follow the structure of the six-part series with one section for each paper in the series followed by a final section to provide closure. Because this paper is less than one-sixth the length of the series, neither the discussion nor the reference list can be as thorough as the original series. Our goals are to answer the four questions listed above, to provide a short guide to the pertinent literature from the intervening 16 years, and to motivate readers to read or re-read the original six articles.

1. A VISION FOR ENGINEERING EDUCATION

Predicted challenges for engineers were: increasing rate of information proliferation, engineering practice requiring several disciplines, global markets and global competition, clearly endangered environment, emerging social responsibility, leaner corporate structures, and rapid change.^[1] With the exception of emerging social responsibility, which is still developing, these predictions have proven to be quite accurate.

Components of engineering education

Rapid change has shifted the appropriate balance between teaching immediately useful material and laying the foundation for growth. Because of the large number of employment possibilities for engineering students (considerably larger than in 2000), a curriculum that provides all the knowledge that all graduates might need in any job is impossible to design. One possible solution is to alter the curriculum by incorporating tracks such as bioengineering, nanoengineering, petroleum refinery engineering, or energy/sustainability that allow specialization; however, keeping these tracks current will be a significant challenge as the “hot” technologies change. Some chemical engineering departments have chosen to restructure their entire curriculum to achieve specific learning goals, including Worcester Polytechnic Institute’s project-based spiral curriculum^[9,10] and the University of Pittsburgh’s Pillars block scheduled curriculum.^[11] A second possible solution is to emphasize fundamentals and lifelong learning. However, most graduates still need some basic tools such as facility with mass and energy balances as well as more advanced tools such as spreadsheets and commercial simulators that make them immediately productive in an entry-level position.

However, technically productive engineers are often promoted based on other skills. Thus, the professional skills delineated in ABET criteria 3 (d, f-j)^[1,12] need to be taught, practiced, assessed and critiqued, and practiced again until they are mastered at an acceptable level. Although teaching knowledge scales up reasonably well, teaching many skills, such as oral communication, does not. In addition, the faculty is more comfortable teaching knowledge [Section 2] than skills [Section 3].

Although some professors may believe it is not their job to try to teach attitudes and values, the authors of the series^[1] and we believe that it is. Faculty wants students to be honest, and students who cheat regularly are more likely to behave unethically after graduation.^[13] The AIChE code of ethics^[14] includes “Being honest” and “Using their knowledge and skill for the enhancement of human welfare.” All engineering codes include “the overriding importance of competence, responsibility, accountability, and fairness.”^[15, p. 141] Recently there has been a push to instill in students the value that engineers should serve the public and enhance social justice.^[16-19] The Engineering Projects in Community Service (EPICS) program,^[19] Engineers Without Borders,^[18] and other service-learning initiatives and organizations have highlighted opportunities for engineers to use their skills to serve the community.

Change in engineering education?

Although there are encouraging signs of change in the teaching of engineering, the obstacles to change remain formidable. Despite these obstacles, the authors were optimistic: “The presence of hard evidence to support claims of improvement in learning should make it easier to disseminate educational reforms to the skeptical mainstream engineering professoriate.”^[1, p. 23] Sixteen years later, it looks like their prediction about the rate at which active learning would permeate engineering education was overly optimistic.^[20] On the other hand, probably because of faculty research interests and funding availability, chemical engineering departments have rapidly incorporated bioengineering, nanoengineering, energy/sustainability, and, to a lesser extent, engineering education into their research portfolios. Many of these topics are now found in both graduate and undergraduate courses.

There also appears to be a welcome shift away from “the myth of the superhuman professor”^[21] who could do everything and therefore did everything. Chemical engineering departments are slowly developing more specialized positions such as researcher professors (perhaps on soft money) who may also teach graduate students, entrepreneurial professors who start new companies, teaching professors who mainly teach undergraduates, professors of practice to compensate for the faculty’s lack of industrial experience, and well-trained staff who have taken over many duties such as advising and serving as the department head’s chief of staff. In addition, there is increased use of resources not developed in-house such as companies providing online homework,^[22] YouTube videos,^[23] screencasts,^[24] the AIChE Education Division Concept Warehouse <http://jimi.cbee.oregonstate.edu/concept_warehouse/>, and so forth. In the past the only commonly used outside resource was the textbook, a resource that may disappear in its current form.^[25] Publishers are

responding by offering online content to complement new textbooks, including online algorithmic problems, reading quizzes, tutorials, videos, and other interactive resources for both students and instructors. Current chemical engineering departments already look different, and certainly the departments of the future will not look like chemical engineering departments in 2000.

2. TEACHING METHODS THAT INCREASE STUDENT LEARNING

Research shows that writing and sharing learning objectives, showing real-world relevance of course material, teaching inductively, balancing concrete and abstract information, using active-learning methods in class and cooperative learning in and out of class, giving fair but challenging tests, and conveying a sense of caring about students' learning will improve the quality of learning that occurs in the classroom.^[2,26-31] All of these methods can be incorporated in any course, typically do not require sophisticated technology, and can be practiced at varying levels of detail and expertise depending on the comfort level and commitment of the instructor.

Learning objectives

The authors of the Future series could probably see that ABET EC2000 would help to institutionalize the use of learning objectives (see Section 5). Because of their more active and ongoing involvement in the accreditation process, faculty are generally more comfortable today than they were in 2000 with the idea of establishing learning objectives, linking homework and exams to each learning objective, and assessing student performance. The key idea the authors wanted readers to get from their paper^[2] p. 37 was "Writing formal instructional objectives and using active and cooperative instructional methods offers a good prospect of equipping your students with the knowledge and skills you wish them to develop." They suggested that instructors write objectives at the course and lecture levels, and give students a list of detailed objectives as an effective study guide for exams.^[2,32] This advice remains relevant today.

Active learning

Table 1 (next page) lists various methods with a short description, advantages, disadvantages, and references. As the authors warn in Part 2 of the original series, "an instructor who sets out to implement all of the suggestions in this paper is likely to be overwhelmed in the attempt and to end by implementing none of them.^[2] Instructors seeking to apply new teaching methods are best served to choose one or two approaches, take note of how they work, make changes as needed, and then add new approaches slowly to avoid getting overwhelmed or having students feel like guinea pigs.

In addition to the general methods listed in Table 1, specific active-learning methods have been developed for chemical engineering core courses.^[33,34]

Cooperative learning

Cooperative-learning structures^[2,35] include both traditional structures, such as having students work together on problem sets, laboratories, and projects, as well as more complex arrangements, including jigsaw (in which team members have expertise in different areas), peer editing of written documents, and peer-led team learning (PLTL).^[36,37] Applications can be as simple as think-pair-share and TAPPS to more complex structures. Widely used in STEM education, team-based learning (TBL),^[38] peer-led team learning, and process-oriented guided inquiry learning (POGIL)^[39,40] are examples of learning formats that have been shown to produce positive learning outcomes. Typical difficulties encountered in the application of cooperative learning include student resistance and dysfunctional teams, which can often be diffused if the cooperative-learning structure satisfies the criteria of positive interdependence, individual accountability, face-to-face promotive interaction, development and appropriate use of teamwork skills, and regular self-assessment of team functioning.^[2,35]

3. HELPING STUDENTS DEVELOP CRITICAL SKILLS

ABET's emphasis on critical skills in EC2000^[12] further highlighted the need to train students in the areas of problem solving, writing, teamwork, self-assessment, lifelong learning, and change management.^[47-49] Woods, *et al.*^[50] highlight feedback from business and industry on expectations of new graduates and offer specific suggestions on development of skills in communication, problem solving, time management, decision making, teamwork, critical thinking, self-confidence, trust, and stress management. Strategies for teaching creativity and problem-solving skills are detailed in a number of references.^[3,26,51,52]

One new development since 2000 is that online tools such as CATME^[53] support the process of skill development by providing resources to assign students to teams based on instructor-specified criteria, automate self- and peer evaluations, train students to rate teamwork skills, train students to work in teams, and make student team meetings more effective. Training students in these skills will improve the performance of teams in cooperative learning and problem-based learning.

There remains broad agreement that communication skills (ABET criterion 3g) are critically important for engineers^[47,50] Engineering instructors have been challenged to integrate

writing and speaking instruction within the core courses.^[54] While this type of instruction typically occurs in laboratory courses, capstone design courses, or professional development courses,^[55,56] writing can also be an effective tool for in-class responses to ConcepTests or “muddiest point” reflections.^[57]

Development of these critical skills is easier to foster in a studio, workshop, or problem-based learning (PBL) environment^[52,58-61] than in traditional lecture format. Instructors may

want to first get comfortable using active and collaborative learning approaches before moving to a PBL or workshop/studio-based approach. An online tool, ChemProV, in which students provide and receive critiques of flowsheet construction and labeling, has been used in a studio-based learning approach to the material and energy balance course.^[62]

4. LEARNING HOW TO TEACH

In a different era when teaching was the primary job of

TABLE 1
Examples of active learning approaches

Method	Description	Advantages	Disadvantages	Refs.
Individual Exercises	Give students 2 minutes to complete a task. Call on one or more students to share their responses, discuss, return to lecture.	Easy to integrate into lecture course. Takes only few minutes. Allows introverts time to think and process the material.	Students may panic when you call on them. Extroverts may get antsy and want to talk to their neighbor.	[41]
Small-Group Exercises	Put students in small groups (2-4) to work on an assigned task.	Students have the support of a classmate in developing a response. Builds community within the classroom.	Fixed seats make forming small groups difficult. After activity, must regain students' attention. A few groups may be dysfunctional.	[2]
Think-Pair-Share	Students work alone, then in pairs compare and improve responses. Ask pairs to share.	Individual reflection can lead to more and deeper learning.	Takes time. Although pairs are less likely to be dysfunctional than groups, it still occurs.	[2]
Thinking Aloud Pair Problem Solving (TAPPS)	Students work in pairs, alternating in the role of problem-solver and questioner.	Often deeper student understanding of the topic compared to other teaching methods.	Takes time to execute. Pairs may be dysfunctional.	[2]
Notes With Gaps	Provide students with lecture notes that leave gaps or blank spaces.	Provides time for examples and difficult concepts.	Students may not attend class if you provide notes in advance.	[42]
Chunked Problem Analysis	Break problem into small chunks. Quickly lecture through easy parts and have students work through harder parts.	Works well with notes-with-gaps. Students own the material and are more confident working problems on their own.	Takes time to execute.	[2]
Concept Tests + Clickers	Conceptual multiple choice questions used to improve understanding.	Obtain immediate feedback to identify student misconceptions.	Instructor's questions may excessively focus on the knowledge level of Bloom's taxonomy.	[43] [44]
Flipped Classroom	Students study materials (textbook or online) before class. Class time used for problem solving and skill development.	Students master basic material prior to class, which provides time for group work and other active learning methods.	If students fail to prepare for class, the in-class activity can be unproductive.	[42]
Guided Reciprocal Peer Questioning	Students use question stems that promote high-level thinking to formulate questions about assigned readings and quiz one another in class.	Promotes critical thinking and reading skills. Can be combined with flipped classroom.	Takes time to execute. If students do not prepare in advance, can be unproductive.	[45]
Explain Worked-Out Examples	Hand out derivations or problem solutions. Students explain them to one another and then to you, step-by-step.	Instead of having to master the “how” of every step, students can focus on the “why.”	Takes time to execute. Not as useful if students have no idea what to do.	[26] [46]

engineering faculty, faculty learned to teach by on-the-job practice, and many of the faculty eventually became good teachers. In that era there was considerable informal support to improve teaching, and time to improve was made available. Currently, at research universities, research is the main job of engineering faculty, and the pressure to get off to a fast start in research and proposal writing is intense. As a result, there is less time and informal support for improving teaching. Unfortunately, there has been little change in graduate school training since 2000, and most new engineering faculty are still not well prepared for their roles as educators.^[63,64]

How does one learn to teach?

Learning to teach is similar to learning how to do any fairly complex task that involves both knowledge and performance skills:

1. *Become involved.*
2. *Find an enthusiastic teacher and/or teaching mentor.*
3. *Expect to improve.*
4. *Learn required knowledge (information) and skills (lecturing, facilitating active learning, etc.).*
5. *Practice (do it), reflect on the practice, obtain feedback (from teaching mentor and from students), incorporate reflections and feedback in your methods, and repeat.*
6. *Spend time on task.*
7. *Accept challenges, but at a level at which success is possible.*

Courses and workshops have the advantages of structure, an expert is available to answer questions, and because of the support of peers and the instructor, it is easier to go outside of your comfort zone. The instructor will probably demonstrate effective teaching methods that attendees were never exposed to as students, and there may be opportunities to practice some of the skills required and develop a plan for applying the newly learned material later. Effective teaching courses and workshops generally cover basic pedagogy and teaching methods that have been known for years. Usually, the only new information is the scientific proof that the methods work. In addition, finding a teaching mentor at your home institution who enjoys discussing teaching and who can occasionally attend your classes is very helpful.

What about having graduate students who are considering a career in academia take an education course during their graduate training? Some aspects of teaching are difficult to understand and appreciate before one has actually taught; in addition, many faculty may be less than enthusiastic about having their graduate students spend time taking an education course. However, regular three-credit graduate courses

on teaching can cover material in significantly more depth than a three- to five-day workshop. Although they may not believe it, graduate students and post-docs have more time than they will have when they start in a permanent academic position, and taking such a course will equip them to be more successful if they become new faculty members.^[65]

Ideally, future academics would participate in a structured series of teaching/learning experiences. They might start with a short workshop for teaching assistants (TAs) and then serve as a TA. After this experience, they could take a graduate course on teaching. Supervised teaching experiences either as interns in a Preparing Future Faculty Program^[66] or sharing courses with professors^[67] would provide hands-on practice. As either senior Ph.D. students or post-docs, they could be completely in charge of a course, but would be expected to have regular meetings with teaching mentors. After teaching for a few years, attending an extended workshop will help them develop a more mature understanding.

Two examples of exemplary workshops are the three-day ASEE National Effective Teaching Institute (NETI) held immediately before the ASEE annual meeting, and the week-long ASEE Summer School for Chemical Engineering Faculty^[68] held every five years. The Summer School includes sessions on pedagogy as well as new content for both core and elective courses.

Evidence that teaching courses and workshops are effective

One change since 2000 is that the evidence is now much clearer: Courses and workshops on pedagogy improve teaching.^[4,42,64,65,69–72] Attendees at Succeed Coalition workshops later self-reported an increase in use of active-learning methods.^[69] Graduates of a three-credit graduate course on teaching engineering stated several years after starting as assistant professors that the course was immensely helpful in their teaching and in freeing time for research.^[65] The graduates strongly recommended that future academics take a similar course. Science professors had a significant increase in teaching ratings after enrolling in a three-credit course, and the increase was retained years later.^[70] Graduates of the NETI reported a significant increase in their teaching ratings^[71] and in their adoption of student-centered teaching practices.^[72] Professional development activities such as workshops were shown to be positively related to the use of student-centered teaching practices.^[64] There was also modest evidence that graduate training was effective, but the small numbers of professors with such training resulted in lumping all types of training together for assessment purposes.^[64] Ongoing work with Virtual Communities of Practice sponsored by NSF^[73] seeks to address the challenge of making training more widely available and cost effective as well as building learning communities for faculty with a common interest.

5. ASSESSING STUDENT LEARNING, EVALUATION OF TEACHING, AND ENGINEERING EDUCATION SCHOLARSHIP

Although assessing student learning is an excellent method of evaluating teaching, we will follow the pattern of the original series and treat assessment and evaluation as separate topics. Engineering education scholarship was added to Part 5^[5] apparently because it is also involved with improving education.

Assessing student learning

ABET EC2000 spelled out five technical and six professional outcomes that students should have achieved by graduation,^[12,48] and “ABET (a)-(k)” became part of the faculty vernacular. After considerable gnashing of teeth^[74] in the late 1990s and early 2000s, faculty realized that direct faculty assessments of student learning of technical outcomes were straightforward.^[75] If course outcomes are first defined and then homework and test problems are developed that assess only one outcome,^[32,76] direct assessment becomes a natural part of grading. Unfortunately, tests often do not provide as accurate an assessment of the students’ practical abilities as do projects that are closer to industrial practice.^[5]

Assessment of the ABET professional outcomes proved to be more challenging. A combination of indirect assessments (e.g., student surveys and interviews of graduating seniors) plus direct assessment using a rubric (a detailed description of what the students can do at different levels of accomplishment) or a checklist^[5] is effective for assessing professional outcomes. Sample rubrics are available.^[42,48]

Self- and peer assessment methods are most commonly used for assessing team performance.^[49,53] Communication skills can be assessed with portfolios (rarely used in practice) and rubrics.^[42,49] Additional assessment methods that are routinely used for engineering education research include surveys, interviews and focus groups, conversational analysis, behavioral observation, ethnography, and meta-analysis.^[77] Surveys and interviews are commonly used by programs for indirect assessment, but for research purposes, surveys must be carefully validated before use, and interviews are typically audiotaped and transcribed.

Evaluation of teaching

Because summative (end-of-the-semester) student evaluations are often used for administrative purposes,

university procedures should be followed. Properly administered student evaluations are reliable and valid^[5,42] although ratings can be skewed by factors such as the type of course. For example, elective courses are rated higher by engineering students than required courses.^[42,78] The global ratings of the instructor ($r = 0.5$) and the course ($r = 0.47$) have the highest correlations with student exam scores.^[79]

Student evaluations should be, but usually are not, supplemented with other evaluation methods such as peer reviews,^[5,42] teaching portfolios,^[5,80] or course portfolios.^[81] Summative student evaluations and peer reviews rarely result in teaching improvement unless a consultant helps the instructor deal with the issues raised. The reflection required to assemble a portfolio can lead to teaching improvement. Unfortunately, there has been little increase in the use of these methods since 2000.

Engineering education scholarship

Interest in engineering education scholarship and improving the level of scholarship have increased since 2000. Pre-1993 there was very little quality control in engineering education papers. Literature reviews, references, and assessment data were not required. The paradigm was essentially, “I tried it, it worked, and students loved it.” In 1993 the *Journal of Engineering Education (JEE)* instituted a scholarship paradigm^[82] that has been broadly adopted for course and curriculum development by other journals. Ten years later *JEE* adopted a rigorous research paradigm.^[83,84] These two scholarship paradigms, both currently used by different journals, are contrasted in Table 2. Since the scholarship paradigm used by *CEE* is accessible, all ChE professors can contribute to the ChE pedagogy knowledge base. However, the interpretation by some researchers that the rigorous research paradigm is “better” has tended to divide theoreticians and practitioners in the engineering education community.^[85]

Another major change since the publication of the series is the increased acceptance of engineering education research as a legitimate research area for engineering faculty. Since 2004 several colleges of engineering in the United States and abroad

TABLE 2
Engineering education scholarship paradigms

Engineering education scholarship paradigms	
Scholarship paradigm for course and curriculum development	Rigorous engineering education research paradigm ^[83,84] [Lohmann, 2003, 2008]
<ul style="list-style-type: none"> • Original^[82] from Ernst [1993]. • Short literature review & references including pedagogical literature. • Data: Student surveys and evaluations. • Paper should be interesting! • Level expected by <i>CEE</i>. • Level is accessible by all ChE professors. 	<ul style="list-style-type: none"> • Hypothesis in advance. • Test during research. • Thorough literature review. • Ground research in learning theory or human development theory. • Mix quantitative and qualitative methods. • IRB approval in advance. • At quality level of best educational journals.

have established Ph.D.-granting programs in engineering education. In addition, engineering education is an explicit area of scholarship in some traditional chemical engineering departments like Oregon State (<<http://cbee.oregonstate.edu/research>>,^[86,87] who allows chemical engineering Ph.D. theses to be on engineering education, and Washington State (<<http://www.voiland.wsu.edu/research.html>>), who allows Ph.D. theses with a portion in engineering education when there is a clear link between the teaching/learning part and a disciplinary advance. Washington State students who desire to focus primarily on engineering education, with less of a technical thrust, can do so by seeking a Ph.D. in engineering science administered by the associate dean of the College.

6. MAKING REFORM HAPPEN

Paper 6 in the original series^[6] was a strong call for reform of engineering education. Calls for reform of engineering education became stronger with the publication of the NAE reports, *The Engineer of 2020*^[88] and *Educating the Engineer of 2020*.^[89] Unfortunately, despite the optimism of the original authors,^[1,6] we are a lot closer to the year 2020 than we are to making reform happen.

There is clear scientific evidence that teaching reforms increase learning^[2,3]; however, the mainstream engineering professoriate remains skeptical.^[74] Unfortunately, the dissemination-of-knowledge model that assumes research will convince faculty to change their teaching methods has not worked.^[20] Disseminating research results will usually fail if the research does not have a practical focus, the language used is not common for the intended users, and users do not have a knowledge background sufficient to understand the results.^[90] Engineering education research often does not appear practical to engineering professors teaching technical material. In addition, since the majority of engineering professors have no pedagogical training, the language used by researchers is unfamiliar, and the basic knowledge structure is lacking.

Three successful historical chemical engineering education reforms were^[20] (1) AIChE's use of accreditation to base chemical engineering education on unit operations instead of industrial chemistry,^[91] (2) the engineering science revolution after World War II,^[92,93] and (3) the change in accreditation of engineering programs from an input to an outcome model that improved the teaching of professional aspects.^[74,93] Both sticks and carrots encourage people to change. The first and third reforms had the stick of accreditation. The second reform had the sticks of Sputnik and the fear of falling behind the Soviet Union plus the carrot of NSF money for engineering research.

Lattuca, et al.^[64] found that the interests of faculty were the most important factor in their use of student-oriented teaching

methods, but very few of the faculty they studied had been trained in pedagogy. Once the faculty is trained in their use, many active-learning methods take the same or less time than lecturing.^[42] Surveys of professors at four-year institutions typically show half the professoriate are more interested in teaching and half are more interested in research.^[94,95] Faculty not trained in pedagogy and more interested in research are unlikely to make the effort to learn to use active-learning methods.

Reward systems at research universities currently favor research. Although there has been some movement towards more weight for teaching, it has been modest.^[74] Since the influence of faculty reward systems on faculty behavior is frequently overestimated,^[64] the fear of losing control in the classroom^[11] and the fear of failure^[96] are probably more important factors in the slow adoption of active-learning methods. Training in pedagogy reduces fear of failure.

A prerequisite for significant reform is establishing instructional development programs.^[6,20] Engineering education reform will not occur until at least one of the national organizations with carrots (NSF), sticks (ABET), and prestige (NAE) sends the unequivocal message that faculty must be trained in pedagogy.

7. CLOSURE AND A CHALLENGE FOR PERSONAL ACTION

Briefly, our answers to the four questions posed in the introduction are:

1. **How accurate were the predictions?** *Except for predictions on the pace of reform of engineering education, the predictions were basically accurate.*
2. **Is the advice in these papers still current?** *The advice offered in the original series remains current.*
3. **What advances in our understanding of teaching and learning in engineering education have occurred since the turn of the century?** *The scientific basis for suggested teaching and learning strategies is much stronger. In the near future neuroscience may lead to major breakthroughs in how people learn.^[97]*
4. **Has reform of engineering education been successful?** *Despite new scientific knowledge about both teaching and learning, significant transformation of engineering education remains elusive.*

The cost of traditional on-site college education keeps rising with little improvement in the overall quality of teaching, while the quality of alternative education increases as costs drop. In addition to predicting the demise of straight lectures and textbooks, Richard Felder, the lead author of "The Future of Engineering Education," predicts^[25] that within 10 years,

increasing numbers of students will turn to credit-granting Massively Open Online Courses (MOOCs), causing a major shakeup in higher education. We agree with Felder, with three modifications: (1) Students will also pursue additional methods for learning and obtaining credit, including the successful Open University method^[98] that can be characterized as a MOOC plus tutorials, advanced computer-aided instruction^[42,99] perhaps with tutorials, and standardized test-out procedures such as the College Board CLEP tests^[100]; (2) engineering students will probably attend a bricks-and-mortar institution for the last two years of their degree; and (3) change will be rapid once a critical threshold is passed, but it may take years to reach the critical threshold. Perhaps student abandonment of traditional universities will ultimately serve as a catalyst for significant reform of engineering education.

If your teaching can be replaced by a video, eventually it will be. If your department can be replaced by an online degree-granting institution, eventually it will be. To avoid obsolescence, add value that cannot easily be provided by video or technology. Show your students you care about them, provide mentoring and personal attention, and create a culture that builds community within the classroom and the department.^[101] Use active learning^[2]; engage students in projects, design, and laboratory experiences that prepare them for professional practice^[15]; and provide skill training^[3] in change management, communication, leadership, problem solving, teamwork, and other skills that are more difficult to learn remotely.

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