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THE FUTURE OF ENGINEERING EDUCATION
VI. MAKING REFORM HAPPEN

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We have dealt in this series with changing conditions in technology and society that will require major reforms in engineering education,[1] instructional techniques that have been shown by theoretical and empirical research to produce learning outcomes consistent with these reforms,[2,3] ways to prepare faculty members to implement the techniques,[4] and effective techniques for assessing both teaching and educational scholarship.[5] Those were the easy matters. The real challenge is to create a favorable climate for these changes at research universities—a climate that motivates faculty members to improve their teaching and the quality of instruction in their departments, supports their efforts to do so, and rewards their successes. In this paper we suggest steps that might be taken to create such a climate.

THE FALL AND RISE OF TEACHING AT RESEARCH UNIVERSITIES

Evidence of the low status of undergraduate education at research universities for the past half century is easy to find. Every campus has its stories of outstanding teachers being denied tenure because their record of research funding and publications was judged inadequate. Tenured professors commonly warn their non-tenured junior colleagues not to spend too much time on their teaching, telling them that a teaching award before tenure is the "kiss of death."

Growing numbers of administrators and faculty members acknowledge that a problem exists. Gray *et al.*[6] surveyed over 23,000 academics in 47 United States universities and concluded that many faculty, chairs, deans and academic administrators at research universities believe that an appropriate balance between research and undergraduate teaching should exist but does not now exist at their institutions. Knapper and Rogers[7] report a similar result of a recent extended survey that included Canadian faculty and administrators. Faculty members of the eight campuses comprising the SUCCEED Engineering Education Coalition were recently asked to rate the importance of teaching effectiveness to them, to their colleagues and administrators, and in their institution's faculty reward system, with 0 being not at all important and 10 being extremely important.[8] On average, the 504 respondents rated the importance of teaching to them personally at 9.3, the importance to their colleagues and administrators in the range 7.0–7.3, and the importance in the faculty reward system at 4.7. In the respondents' open comments about administrative support for teaching, the term "lip service" came up with remarkable frequency.

The teaching and assessment methods described in the first five papers can be used by any instructor at any institution, but while most of them do not require a heavy allocation of resources, they all require time and effort to learn, implement, and refine. As long as faculty members feel that their efforts to improve teaching will be largely unappreciated and unrewarded—and in fact could jeopardize their chances for advancement up the faculty ladder—educational reform will be difficult to achieve. In such a climate, the temptation is great to just dust off the old notes and teach the way they were taught.

On the brighter side, a positive shift in campus attitudes toward teaching began in the early 1980s and has grown steadily since then. There were several catalysts for this shift, including reports by the National Research Council, the National Academy of Engineering, and the American Society for Engineering Education that called for reforms in engineering education.[9] Another driver for change was a growing chorus of complaints from employers of engineers about deficiencies among recent graduates in the skills needed for success in modern engineering practice.[9–10] Responding to these calls, the National Science Foundation began to provide significant funding for education-related research and to consider the impact of proposed research on education in its proposal review process, and ABET adopted the outcome-based Engineering Criteria 2000 as its accreditation standard beginning in 2001.[11] Administrators and faculty members are beginning to recognize that new instructional methods and materials will be required to receive continued accreditation if that standard is rigorously enforced.

Evidence for the growing importance of effective undergraduate instruction at research universities is abundant. Presentations at ASEE conferences and submissions to the *Journal of Engineering Education* have grown dramatically in both number and quality. Tested innovations in teaching methods, technology-based instruction and distance education, assessment and evaluation of teaching and learning, design across the curriculum, and multidisciplinary curriculum integration are described with increasing frequency in the literature.[12] Teaching seminars and workshops are regularly presented to engineering faculty and graduate students on campuses where nothing of the sort had ever been done. In its annual offerings from 1991 through 1999, the National Effective Teaching Institute has reached 472 professors of engineering and engineering technology from 157 institutions, many of whom have gone back to present programs on their home campuses. These are indeed exciting times for engineering education.

It is not yet time to break out the champagne, however. The dramatic progress made in recent years notwithstanding, most engineering classes still consist of professors talking and writing on the board and students sitting and listening (or not listening); rigorous assessment of learning and teaching is still not part of the culture of most institutions; faculty members are still not routinely given any preparation for teaching; and senior faculty are still advising junior faculty (often correctly) that if they spend too much time on their teaching they could be jeopardizing their future academic careers.

Most faculty members are reluctant to move away from the familiar and comfortable teaching methods with which they were taught, especially if they believe that changing methods will require substantial expenditures of time and could hinder their chances for tenure and promotion. They will only consider doing so if they are first made aware of the need for change, presented with alternative methods, given convincing evidence of the effectiveness of the alternatives, and assured that adopting the methods does not necessarily require sacrificing syllabus coverage or spending less time on research. A prerequisite for significant educational reform is therefore the establishment of instructional development programs that provide this information and these assurances. Another necessary condition for reform is for faculty members to be convinced that their efforts to improve teaching will not work against their career advancement, and that if successful, the efforts can in fact work in their favor.

Descriptions of the need for change, alternative teaching methods, and evidence of the effectiveness of those methods are given in the first five papers in this series. The next section suggests how faculty members can make meaningful improvements in teaching without spending excessive amounts of time or shortening their syllabi, and how they can deal effectively with student resistance to student-centered teaching methods. The section after that proposes tangible steps that administrators might take to make their campus culture supportive of educational reform.

RESPONSES TO FACULTY CONCERNS ABOUT ALTERNATIVE TEACHING METHODS

Finding Time to Plan and Implement Changes

In their teaching workshops, the authors caution the participants that if they try to implement every new technique they hear about, they will probably be overwhelmed by the time they find themselves spending and the student resistance they encounter, get discouraged, and go back to old ways of doing things. Instead, they are advised to select only one or two ideas at a time and try them long enough for the students to acclimate to the new methods. If a method seems to be working well, they should keep on using it; if it seems to be ineffective, they should first check back in the literature to make sure that the recommended guidelines have been followed, and if they have, discontinue it. Some time later (perhaps in the following semester or quarter), they might try another one or two new ideas. There is no hurry.

Many effective instructional strategies take relatively little time to plan and implement, several of which are listed below. Instructors who have been teaching traditionally and wish to make changes might consider trying one or two of these strategies first, consulting earlier papers in the series for details:

- Motivate the presentation of each new topic by relating it to previously learned material and familiar applications, perhaps starting with a realistic problem or illustrative case study.
- Write clear instructional objectives for course topics and give them to the students as study guides for tests.
- Assign brief small-group activities in class (have the students respond to questions, formulate questions, begin problem solutions, carry out steps in problem solutions and derivations, brainstorm ideas,…)
- Have students complete one or two out-of-class assignments in teams (rather than moving immediately to full-scale formal cooperative learning).
- Periodically ask students to monitor and reflect on their learning, either in the form of minute papers (What was the main point of the lecture? The muddiest point?) or using feedback forms collected at the end of a lecture period. The instructor need only skim the responses to look for patterns and begin the next class by responding to common points of confusion; it is not necessary to provide individual feedback on every response.
- Collect midterm evaluations of the class. (What am I doing in this class that is helping you learn and you would like me to continue to do? What am I doing that is hindering your learning and you would like me to discontinue?) Respond to any reasonable suggestions made by more than two students, accepting those you wish to accept and explaining why you will not go along with the others.

Once comfortable with these strategies, instructors should gradually move on to methods that involve greater departures from usual teaching practice and take more time to implement.[2,3]

Covering the Syllabus

At teaching workshops that advocate active and cooperative learning and other student-centered instructional methods, the first question is almost invariably a version of "Can I do all that without sacrificing coverage of important course content?"

Our initial response to this question is that the goal of teaching is not to cover material but to *un*cover it. Virtually all cognitive scientists agree that people learn by doing and reflecting, not by watching

and listening to someone else tell them what they are supposed to know.[13] Instructors can present almost any amount of material in any amount of time by using transparencies or presentation graphics and talking quickly enough, but there is not much point in doing so if hardly any of the material is being learned.

Having said that, we add that using active learning does not require reducing the syllabus. It is true that in-class activities take time (although not nearly as much as instructors who have not used them fear), and if these activities are included in classes and no compensatory changes are made, content coverage might indeed decrease. Compensatory changes *can* be made, however. Felder and Brent[13] propose that instructors take large chunks of the lecture material they usually present explicitly in class—the complete step-by-step derivations, sentences, flowcharts, schematics, and plots—and give them to the students in handouts or a coursepack. The handouts should include gaps—missing steps in derivations, axes with no curves shown, questions and problems with spaces for answers to be filled in. The students can skim through short sections of the notes during class, and the instructor can either lecture on the gaps, get the students to work in small groups during class to fill them in, or leave the gaps to be filled in outside class. The instructor should caution the students that he/she will put variants of the gaps on the tests and then do it.

If this recommendation is followed, most students will read the notes and make sure the gaps get filled one way or another—at least after the first test, when they discover that the instructor was serious about including them. Class sessions can now be devoted primarily to the most important and/or conceptually difficult material in the lecture notes, and the students will have opportunities during those sessions for the action and reflection that lead to true learning. The class time the instructor saves by not having to spell out every word and formula in the lecture notes is sufficient to allow for all the active learning exercises he/she might wish to include, and the syllabus may actually be expanded to cover *more* material rather than less.

Defusing Student Resistance

Students do not always welcome unfamiliar teaching methods with open arms, especially if the new methods push them out of the comfort zone in which the instructor tells them everything they need to know and then asks them to repeat it on the test. Students introduced to active learning, for example, sometimes accuse their instructors of not doing their jobs when they require the students to learn some things on their own. This hostile reaction is extremely disturbing to instructors who are not expecting it and don't know how to deal with it, and many who encounter it become discouraged and revert to the less effective but safer lecture-based approach.

The occurrence of student resistance is familiar to anyone who has attempted a student-centered instructional approach like cooperative or problem-based learning.[15–18] Woods[15] suggests that students who find themselves deprived of the support they are used to getting from their instructors go through some or all of the stages that psychologists associate with the grieving process: shock, denial, strong emotion, resistance and withdrawal, surrender and acceptance, struggle and exploration, return of confidence, and integration and success. Some students quickly pass through or even skip some of the stages and others get stuck and never emerge from one of them for the entire semester, but the process is a natural one and instructors should not be surprised when they see its sometimes unpleasant manifestations in their students.

Felder and Brent[17] suggest several things instructors might do to hold down the resistance to student-centered instruction long enough for the students to start seeing the benefits of the approach for themselves.

1. *Start early, start small, and build.* Instructors planning to use a student-centered approach should start using it near the beginning of the course, making their goals and expectations clear from the outset. If they have not used the approach before, however, they should not make it the primary mode of instruction in the course the first time they try it. It is better to take small steps and gradually to increase the level of commitment to the approach, never venturing too far beyond the zone of personal comfort and confidence.

2. *Explain what you are doing and why*. When students are plunged into a new instructional approach—especially one that shifts some of the burden of learning away from the instructor and onto them—they may assume that they are guinea pigs in some sort of experiment and react negatively. Before any of the new methods are implemented, they should be outlined to the class and some of the reasons for using them given, and periodic reminders might be beneficial at several points during the semester. Felder and Brent[17–18] outline several arguments that can be offered, including research results that demonstrate the learning benefits of the methods and statements about the relevance of the methods to the engineering workplace.

3. *Be flexible when implementing new instructional methods*. Some students in every class have unique needs and constraints for which allowances should be made. For example, if students are supposed to work in teams outside class on homework assignments or projects and a student has a full-time job or commutes to campus from a considerable distance, he or she might be permitted to work individually. Several students in a class in the same position could be organized into a virtual team that works together on an Internet chat facility or via periodic conference calls. At a commuting campus where many students would find it difficult to meet outside class hours, the instructor might set up a number of virtual teams or make provision for teams to use some class time to work on their projects.

4. *When all else fails, consult the manual.* If student hostility to an instructional method is excessive or if it seems to be growing rather than diminishing with time, check back in the literature on the method to see if any recommendations (including those just given) have been neglected. If any have, take remedial measures.

CREATING A POSITIVE CAMPUS CLIMATE FOR TEACHING

Excellent teaching has always enjoyed vigorous rhetorical support from university administrators but limited tangible reward or public recognition. Excellent research, on the other hand, yields summer salaries, funds for national and international travel, release from teaching and service responsibilities, merit raises, and most significantly, tenure and promotion.

The components of academic research—fundraising, planning, carrying out and assessing research projects, supervising graduate students, giving seminars, and writing papers, among other tasks—all take a great deal of time. The components of college teaching—learning and implementing effective teaching and assessment methods, designing and updating courses to reflect the current state of the art and meet accreditation standards, and advising and mentoring students—take an equally great deal of time. For most faculty members, time is in severely short supply. If research offers the promise of substantial rewards and career advancement and teaching offers little more than internal self-satisfaction, the only faculty members likely to engage in educational reform are those already deeply committed to teaching excellence. The number of such faculty members has grown rapidly in the past twenty years, but it is still too small to achieve reform of the magnitude that will be required to meet the demands on engineering education expected in the coming decades.[1]

We believe that most university faculty genuinely want to be good teachers. Their desire is not motivated by the prospect of external rewards but by intrinsic motivators such as the sense of accomplishment that comes from equipping students with new skills and self-confidence. For all but the most dedicated, however, intrinsic motivation to teach as well as one can eventually diminishes if the campus culture offers little more than empty rhetoric and a few awards to demonstrate its commitment to excellence in teaching. Sloan[20] suggests—and we agree—that external recognition and rewards for effective teaching are needed to support and reinforce intrinsic motivation to teach well. Gmelch *et al*.[21] and Boyer[22] support this idea, identifying inadequate recognition and reward as a major contributor to faculty stress and burnout.

The need to improve the campus climate for teaching is emphasized in a 1999 report of the National Research Council on transforming education in Science, Mathematics, Engineering, and Technology (SME&T).[23] The fifth "vision" articulated in this report speaks directly to the point:

> *Vision 5: All postsecondary institutions would provide the rewards and recognition, resources, tools, and infrastructure necessary to promote innovative and effective undergraduate SME&T teaching and learning.*

The report notes that if Vision 5 were to be realized, universities "would recognize and appropriately reward faculty leaders and departments or program units that have introduced new teaching and learning methods into their courses and curricular programs," recognition and rewards that the Council clearly believes are not currently in place.

Motivated by pressures from respected organizations like the NRC and from industry, governing bodies, and accrediting agencies, many academic programs at research universities have instituted measures to improve teaching. Brent and Felder[24] have assembled a list of such measures, which we summarize below. The more of these measures in place on a campus, the more likely the faculty will be to play an active role in efforts to reform engineering education. To avoid excessive repetition, in the remainder of this section we will use "teaching" to be a catch-all term covering classroom instruction, advising and mentoring undergraduate students, mentoring faculty colleagues and graduate students in teaching, and educational scholarship.

To encourage and help faculty to improve their teaching effectiveness:

- Provide funds for travel to education-related workshops and conferences.
- Provide internal grant support—summer salary and/or materials/supply money—for faculty who propose to carry out a specific project related to their teaching effectiveness.
- When giving new faculty start-up money, designate some of it for teaching-related activities
- Purchase good books on teaching—e.g. McKeachie[25] and Boice[26] —and give them to new faculty members, perhaps in conjunction with an orientation workshop.
- Establish and support a Engineering Center for Teaching and Learning that sponsors a variety of teaching improvements for new faculty, experienced faculty, and graduate students.[27] Alternatively, if a campus-wide center already exists, establish a half-time or full-time engineering faculty development coordinator to work with Center personnel on programs specifically for engineers and to help involve engineers in suitable campus-wide programs.

- Institute a Teaching Leaders program in which outstanding engineering teachers are identified and compensated for jointly facilitating teaching courses, seminars and workshops with faculty development personnel[4] and serving as mentors to new faculty members.[4,28]
- Establish an Engineering Teaching Fellows program in which faculty members in their first few years of teaching receive observation and individual consulting by teaching center personnel and regularly attend seminars or learning communities devoted to good teaching and educational scholarship. Provide stipends, travel funds, or some other tangible form of support to the teaching fellows.

To encourage faculty to redesign curricula and courses (*e.g. for distance education or Web-based instruction*):

- Offer summer salary, release time during the semester, and/or the assistance of a graduate student or work-study student for planning the redesign and preparing new instructional materials.
- Offer and support faculty participation in intensive, personalized summer programs with a specific focus (i.e. teaching and learning via the Web).
- Provide funds for a retreat to a team of faculty working on course or program redesign.

To encourage departments to improve teaching or undertake curriculum renewal:

- Devote some of the regular departmental or college seminars to topics related to teaching
- Identify graduate TA's to help faculty members to incorporate technology (e.g., design a course Web site and put class materials on it, design tutorials to help students with a new piece of software) or to update their courses specifically to address accreditation criteria.
- Establish a college of engineering reserve fund to support multi-faculty departmental initiatives to improve instruction, courses, and curricula and to reward departments that demonstrate the success of the initiatives using systematic assessment.

To reward faculty members for excellence in teaching, advising, mentoring, and educational scholarship

- Require faculty members seeking tenure and/or promotion to prepare a teaching portfolio containing evidence of teaching effectiveness and educational scholarship.[5] Have multiple evaluators rate the portfolio using a standardized rating form and reconcile their ratings. Include the results in a meaningful way when making T/P decisions.
- Hold workshops or seminars for senior faculty involved in making T/P decisions to teach them how to evaluate teaching documentation.
- Designate a specific percentage of merit raise funds to be based on teaching performance.
- In preparation for evaluation, early in the school year have faculty determine a percentage for each aspect of their jobs (teaching, research, service, extension) and goals related to each part. Base evaluations and salary recommendations on the predetermined percentage. Percentages might change from year to year as faculty members explore new research and teaching projects and move into new phases of their careers.
- Allocate a portion of merit salary money for outstanding teaching or mentoring.

- Establish numerous small awards and several large awards ($5000 or more) to reward excellence in teaching, advising, mentoring, and educational scholarship.
- Recognize teaching achievements at faculty and advisory board meetings and in departmental and university publicity releases.

Adopting some of these suggestions can enable an institution to improve the quality of its instructional program substantially, especially if the suggestion about taking teaching into account in tenure and promotion decisions is one of those adopted.

SUMMARY

The devaluation of teaching in the faculty incentive and reward structure of most research universities that began four decades ago has begun to reverse; however, much remains to be done before the educational reforms suggested in this series of papers can become part of the mainstream of engineering education. The key is to provide instructional development that informs faculty members about alternatives to traditional teaching and assessment methods—what they are, what the evidence is for their effectiveness, and how they can be implemented without taking excessive preparation time or having to sacrifice important course content.

The time demands imposed by the adoption of student-centered instructional approaches like active, cooperative, and problem-based learning can be minimal as long as new methods are introduced gradually, starting with techniques that do not require much preparation or class time. For example, instructors might motivate the presentation of new course topics with short industrially relevant case studies, hand out instructional objectives in the form of study guides for one or more tests, and include some brief active exercises in class. To compensate for the additional class time taken by these instructional techniques, the instructors can put portions of the lecture notes in handouts or a coursepack, including gaps and questions to be addressed in or out of class. The time saved by not having to say and write everything in the lecture notes should be sufficient to allow as many active learning exercises as the instructor wishes to assign.

Another concern that makes faculty members reluctant to move to more student-centered instructional approaches is the fear (often based on experience) of student aversion to these methods. Starting slowly and gradually increasing the use of such approaches serves to minimize student resistance. In addition, instructors should explain to the students what they plan on doing and their reasons for doing it, including some published research results attesting to the learning benefits of the approach to be used. Instructors should also avoid rigidity in the application of the methods, recognizing that some students have unique time constraints and other problems that should be dealt with on an individual basis.

Convincing faculty members that alternative teaching and assessment approaches lead to effective learning and addressing their concerns about implementation of the approaches are necessary but not sufficient conditions for educational reform. Before most engineering faculty members will be willing to invest much time and energy to improve teaching, they must be convinced that teaching improvement is truly valued by their institution and that their efforts will not limit their prospects for tenure and promotion. A list of possible steps that institutions can take to communicate that message is presented in the paper. The steps include establishing and supporting workshops and mentorships for new faculty members and graduate students, providing grants and release time for efforts to update and improve the effectiveness of curricula and courses, recognizing and meaningfully rewarding excellence

in teaching, advising, mentoring, and educational scholarship, instituting formal procedures for assessing teaching performance and educational scholarship, and taking the results into account when making decisions on tenure, promotion, and merit raises. The latter step alone could be sufficient to raise the quality of an institution's instructional program to a level that exceeds the expectations of the most idealistic proponents of educational reform.

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