THE SCHOLARSHIP OF TEACHING AND LEARNING IN ENGINEERING*

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Abstract

Engineering professors**,** like professors in every field, have always experimented with innovative instructional methods, but traditionally little was done to link the innovations to learning theories or to evaluate them beyond anecdotal reports of student satisfaction. More scholarly approaches have become common in the past two decades as a consequence of several developments, including a change in the engineering program accreditation system to one requiring learning outcomes assessment and continual improvement, and the literature of the scholarship of teaching and learning in engineering has grown rapidly. Most published studies have used surveys and quantitative research methods, approaches with which engineers tend to be relatively comfortable, but studies that use some of the qualitative methods characteristic of social science research have also begun to appear. The challenge to engineering education is to make the scholarship of teaching and learning equal to the scholarships of discovery, integration, and application in the faculty reward system.

Introduction

Engineering education has had a rich tradition of educational innovation, but until the 1980s assessment of innovation was typically of the "We tried it and liked it and so did the students" variety. A more scholarly approach began to emerge when the National Science Foundation began allocating major funding to educational research and development, with serious assessment planning being a requirement for successful grant proposals. Another major catalyst came in the mid-1990s when the Accreditation Board for Engineering and Technology (ABET) developed a new standard, *Engineering Criteria 2000*. To be accredited, instructional programs in engineering and engineering technology must now set forth learning objectives that involve both technical and interpersonal skills, assessment measures to determine how well the objectives are being met, and plans for taking remedial action to address shortcomings revealed by the assessment. Scholarly approaches to teaching and learning are virtually mandated by these requirements, and considerable progress in developing a scholarship of teaching and learning for engineering has been made in the past two decades.

This chapter surveys the history of American engineering education from its origins in the early 19th century to the present, outlines the development of the scholarship of teaching and learning in the discipline and the challenges to its continuing development, and discusses how it might be assessed to facilitate its inclusion in the engineering faculty reward system.

A Brief History of Engineering Education

Although engineering was first taught in the United States at the Military Academy at West Point in the early 1800's, throughout the 19th century most engineers served apprenticeships with little formal schooling in engineering (Grayson 1993; Reynolds and Seely 1993; Seely 1999). Even well into the 20th century the curriculum retained the practical nature of apprenticeship, including a large number of shop,

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drafting, and laboratory courses, and practical training remained much more important than instruction in theory and mathematical analysis up to World War I. Graduates were expected to be able to function immediately in industry, and professors were expected to have industrial experience and perhaps a master's degree. Teaching was what professors did, and the research done by a small percentage of engineering professors was strictly applied.

After World War I, engineering education started to change as engineering professors emigrating from Europe brought with them a different tradition—more scientific and mathematical, and more involved with research. Subsequent change in engineering education was slow until World War II, when the empirical training of engineers often proved inadequate to meet the growing demands for new processes and materials and the required pace of innovation accelerated dramatically. After the war, Russian successes and early American failures in the space program also highlighted the need for change in engineering education, and large amounts of research funding became available in the 1950s that catalyzed a growing emphasis on academic research in engineering schools.

In 1955, an American Society for Engineering Education committee issued a report (commonly known as the *Grinter Report* after the committee chair, Linton E. Grinter) that called for an increased curricular emphasis on the mathematical and scientific foundations of engineering. The report provided the subsequent basis for instructional program accreditation standards. "Engineering science" began to play an increasingly important role in the curriculum in the years that followed, a trend accelerated by the launching of Sputnik in 1957 and the widespread perception that the United States had fallen behind the Soviet Union in technical capability. This perception led to major changes in pre-college science education, heightened interest in engineering among high school graduates, and increased government appropriations for basic research. The result was that involvement in disciplinary research came to be expected of most engineering faculty members instead of remaining the province of a very small percentage of them.

The importance of research at engineering schools continued to increase in the 1960s, and by the end of that decade the Ph.D. was the standard "union card" of new engineering professors and frontier disciplinary research (the scholarship of discovery) the primary path to promotion, tenure, merit raises, and prestige at research universities. An inevitable consequence was a change in the makeup of the faculty. The professors with extensive industrial experience as practicing engineers or consultants who constituted almost the entire faculty up to the 1950s retired, to be replaced mostly by new Ph.D.'s who had been trained as research scientists and had little or no industrial experience. The effects of the change on engineering curricula were profound (Felder, 1994).

The engineering curriculum prior to the 1950s was a combination of lecture and hands-on instruction closely tied to industrial practice. As engineering science became more important, the hands-on component was reduced, and courses on mechanical drawing and design of engineering equipment were dropped and replaced with courses that emphasized scientific analysis and mathematical modeling. Engineering design (more generally, synthesis as opposed to analysis) and operations were relegated to one or two courses in most engineering curricula. An unexpected side effect of more lectures was an increase in the passivity of students in class.

The changing emphasis from applications to fundamentals in engineering schools did not reflect a similar pattern in the practice of engineering, which involves synthesis no less than analysis and generally follows the "engineering method" defined by Koen (1985): "The use of heuristics to cause the best change in a poorly understood situation within the available resources." A heuristic is anything that provides a plausible aid or direction in the solution of a problem, but is in the final analysis unprovable and fallible. It is used to guide, to discover, and to reveal. Typical engineering heuristics include rules of thumb and orders of magnitude, factors of safety, and heuristics used to allocate resources and to keep risk within acceptable bounds. The senior design course and special topics courses on problem formulation and modeling typically place an emphasis on heuristics (Starfield *et al.* 1994), but engineering students normally do not encounter such courses until they are almost ready to graduate. Many engineering students consequently believe that engineering is much more analytical than it usually is in practice and have difficulty applying the analytical tools to design problems (Sheppard, 2001).

Design is the essence of engineering. Theodore von Kármán (1881-1963) said, "A scientist discovers that which exists. An engineer creates that which never was." Conventional wisdom and much of the early engineering literature presented design as a linear, morphological process, while recent observation and ethnographic research portray it in a dramatically different light. Engineering design is not a totally formal affair: drawings and specifications come into existence as the result of a social process. The various members of a design group can be expected to have divergent views of the best ways to accomplish the design they are working on. Informal negotiations, discussions, laughter, gossip, and banter among members of a design group often have a leavening effect (Bucciarelli, 1994). Engineering schools are only now beginning to incorporate this new understanding of the design process into their curricula. Spurred by NSF support and the requirements of the accreditation process, many have begun to integrate design throughout the entire curriculum rather than relegating it to a single capstone course in the senior year (Ercolano, 1996).

While individual engineering professors have always explored innovative teaching techniques, few instructional approaches developed entirely in engineering have achieved widespread acceptance. One that has is cooperative education, which was started at the University of Cincinnati in 1906 (Grayson, 1993). Co-op programs in which students alternate semesters in school and periods of working in industry continue to be a popular option in engineering education. Another innovation that attracted widespread interest was guided design. Developed in the 1970s by Charles Wales and his colleagues at West Virginia University for use in large-enrollment freshman classes (Wales and Nardi, 1982), guided design has many similarities to problem-based learning, but it is more structured and relies more heavily upon written feedback.

On the other hand, engineering professors have long excelled at adapting innovations and integrating them into engineering education. These adaptations have included mastery learning and the personalized system of instruction, case studies, problem-based learning, and cooperative learning (Wankat and Oreovicz, 1993). Many engineering professors are now experimenting with technology-based instruction and distance learning.

A significant change in engineering education in the past few decades relates to the demographics of the student body. In the 1970s and thereafter growing numbers of women began to enroll in engineering, to a point where the female enrollment in some engineering departments is currently as high as 40% or even higher; however, nationwide only about 18% of engineering undergraduates are female (National Science Foundation, 2000). Also in the 1970s, increasing but still small numbers of underrepresented minorities matriculated in engineering programs. The retention and graduation rates of female students lag behind those of male students at many institutions and the rates for underrepresented minorities have always been well below those of white males. Considerable effort is being devoted to studying the causes of these gaps and exploring measures to overcome them.

Educational changes are taking place even more rapidly in engineering technology education. The mission of technology education is to produce technicians and operators to work with current technology, while that of engineering education is (among other things) to produce engineers to develop the next generation of technology. While related to engineering in many respects, engineering technology uses a more hands-on and less mathematical approach in its instruction. Since it does not have research as a primary component of its mission, it may precede engineering in accepting the scholarship of teaching and learning as part of the faculty advancement process.

The Literature on Teaching and Learning in Engineering

The American Society for Engineering Education (ASEE) has long provided the major forum for exchanging ideas on engineering education across all the engineering disciplines. The flagship publication of the ASEE originally appeared in 1910 as the *Bulletin* and later became *Engineering Education*. For most of its history it was a mixture of newsletter, magazine, and archival journal. An effort to make it more scholarly by publishing one issue every year as *Archives of Engineering Education* met with a mixed reaction from the ASEE members and was discontinued.

In 1991 *Engineering Education* was replaced with two new journals: a new glossy magazine, *ASEE Prism*, which began in September 1991, and an archival *Journal of Engineering Education*, which first appeared in January 1993. *Prism* contains full-length articles, various short features, regular columns (one of which is on teaching and learning), book reviews, announcements, advertisements, and academic employment ads. It promotes improvement of teaching but rarely mentions the scholarship of teaching and learning.

The *Journal of Engineering Education* is now the most widely read chronicle of engineering education research in the United States. According to the Guide for Authors, the *Journal* "seeks articles that enunciate educational principles, rather than simply offer superficial analyses of classroom data and experiments." A regular column in the *Journal* reviews books on all aspects of education. The last two years have seen a surge of interest in learning outcomes assessment as programs begin to be evaluated under ABET's new accreditation standards, and the number of articles on this topic in the *Journal* has skyrocketed.

Other journals devoted to engineering education are summarized in Table 1. *Chemical Engineering Education* (*CEE*), which is published by the Chemical Engineering Division of ASEE, contains some articles of general interest and others of interest only to chemical engineering professors. Likewise, the *IEEE Transactions on Education*, published by the Institute of Electrical and Electronic Engineers (IEEE), is mainly read by electrical and computer engineering professors. The international journals listed in Table 1 are widely distributed in Europe but not heavily read or cited in the United States. Proceedings of the annual ASEE conference and the ASEE/IEEE Frontiers in Education conference are now published electronically but are apparently not used extensively in research studies: no papers from the Proceedings have been cited at a rate greater than once per year in the *Journal* (Wankat, 1999). This situation may change in the future since the *Journal* has recently started reprinting selected *Proceedings* papers.

As Table 1 shows, few books on educational methods in engineering have been written. Books from other disciplines serve as primary references for researchers, however: for example, books by Boyer (1990), Bloom *et al.* (1956), Johnson *et al.* (1991, 1998a), Kolb (1984), Perry (1970), and Tobias (1990) are often cited in *Journal of Engineering Education* articles.

Origins of the Scholarship of Teaching and Learning in Engineering

While research came to be considered an essential engineering faculty pursuit in the 1950s and 1960s, during those decades only one of Boyer's (1990) scholarships counted toward faculty advancement: the scholarship of discovery ("frontier research"). Beginning in the 1970s, growing numbers of faculty members became interested in nationally important problems related to energy production, environmental science and technology, microelectronics, and biotechnology. Recognizing that researchers from several disciplines would have to collaborate to make meaningful progress on solving these problems, the National Science Foundation began to shift its funding away from single investigator research to large multidisciplinary centers, thereby legitimizing the scholarships of integration and application. The scholarship of teaching and learning remained the province of a relative handful of engineering professors through the 1970s. A small percentage of the faculty belonged to the ASEE, a much smaller percentage participated in ASEE activities, and papers reporting on educational research studies never registered on the mainstream faculty's radar screen.

This situation began to change in the 1980s, when substantial support for scholarship in engineering education became available through the National Science Foundation Division of Undergraduate Education and the NSF-sponsored Engineering Education Coalitions program. This support has probably done more to raise awareness of the scholarship of teaching and learning in engineering than any other single factor. It has increased the status of educational research in faculty performance reviews, improved its quality by demanding appropriate assessment of results, attracted additional engineering professors into the arena, and increased collaborations between engineering professors and professors in the social sciences.

Another significant development supporting the scholarship of teaching and learning in engineering was the 1996 adoption by ABET of Engineering Criteria 2000 (EC 2000), a new set of program accreditation standards that emphasize the formulation and assessment of learning outcomes (see <*http://www.abet.org/*>). Between 1997 and 2000 programs could choose to be evaluated under either the old or new system, but starting in 2001 the use of EC 2000 as the standard became mandatory.

The new accreditation system has intensified an interest in educational research and assessment throughout the academic community. As faculty members have come to recognize that changes in pedagogy will be needed to achieve the varied outcomes specified in EC 2000, many of them have begun to develop and assess new methods for achieving those outcomes. Thus, while EC 2000 does not directly require educational research, its adoption has led to a substantial increase in the number of engineering faculty members engaged in this form of scholarship, which has in turn led the engineering education journals to increase their sizes to accommodate dramatic increases in the number of papers submitted. For example, the *Journal of Engineering Education* increased 26% from 405 pages in 1995 to 509 pages in 2000.

In a related trend, engineering schools are starting to realize that something must be done to prepare faculty members to implement the teaching and assessment methods that will be required to meet the new accreditation standards, and campuses are increasingly instituting faculty development programs including courses, workshops, and supervised teaching opportunities for graduate students and workshops and learning communities for faculty (Stice *et al.* 2000). These programs are critically important for the future growth of the scholarship of teaching and learning in engineering, since they produce new professors with the background necessary to contribute as informed readers, reviewers and authors. In 1995 the National Science Foundation funded the first Engineering Education Scholars Program workshop at Georgia Tech. Subsequent week-long summer workshops have been conducted at the University of Wisconsin, Stanford University, Carnegie Mellon University, the University of Illinois at Urbana-Champaign, and the University of Minnesota. These workshops are designed to help early career faculty and advanced graduate students with teaching.

Challenges Associated with the Scholarship of Teaching and Learning in Engineering

Activities that characterize the formal study of teaching and learning in engineering are basically the same as those usually associated with disciplinary scholarship in the field—seeking and securing grant support for research, presenting research results at professional conferences, and publishing them in refereed journals. However, certain differences between engineering research and educational research pose significant challenges to engineering faculty intending to engage in the latter.

Some engineering research is fundamentally scientific in nature. One goal may be to achieve a clearer mechanistic understanding of the underlying causes of an observed physical, chemical or biological phenomenon, such as understanding the chemical mechanisms that underlie the formation of photochemical smog in the atmosphere. Another possible goal may be to construct an accurate model of the effects of specified variables on the behavior of a process or system, such as modeling the effects of chemical spills and subsequent remediation steps on the effluent from a wastewater treatment plant. The phenomena to be studied are objectively defined and observable, and the validity of the proposed theoretical or empirical models can be tested and the results replicated.

Other engineering research is more developmentally oriented, with the goal being to develop a process or product demonstrably superior in specified ways (less costly, stronger or more durable, less hazardous, more energy-efficient,...) to competitive processes or products. Here, too, the processes or products in question are well defined and the success or failure of the effort is easily determined.

Educational research is generally much less precisely defined than engineering research of either type. The ultimate goal of the scholarship of teaching and learning is to improve learning, but it is difficult to find two engineering educators who would agree on what that means. Learning may mean acquisition of knowledge (what knowledge?) and/or deepening of understanding (of what?) and/or acquisition and improvement of both technical and interpersonal skills (which skills?) and/or development of desired attitudes and values (which attitudes and values, and desired by whom?) "Understanding," "skills," "attitudes," and "values" are all highly subjective constructs, unlike "tensile strength," "efficiency," and "profit." Defining them in forms acceptable to most engineering educators is difficult. They cannot be directly observed or calculated, but their existence and level of development must be inferred from observation of student behaviors. Both the identification of those behaviors and the rules of inference are invariably controversial.

It is almost impossible to construct an educational research study in which potentially confounding factors can be clearly identified and their influence eliminated. Students are far more difficult to categorize than I-beams or transistors or even fruit flies, and the factors that influence their learning (including inherited traits, home environments, prior educational experiences, current knowledge and skill levels, learning styles, personality types, and present life circumstances) are virtually uncountable. In consequence, a cause-and-effect relationship between a treatment and an outcome can never be unequivocally demonstrated and replicated. The only way to "prove" anything in education is to run many studies on large populations that point to the same broad result. This is not the kind of reasoning engineering professors are accustomed to employing in their research, however, and most of them are skeptical of it. A large part of the challenge of legitimizing the scholarship of teaching in engineering education involves overcoming this skepticism.

Finally, to improve something one must have a metric for whatever is to be improved (in engineering, a physical property such as tensile strength or flame resistance or an economic variable such as rate of return on investment; in education, specified knowledge, skills, and attitudes) and a set of instruments and procedures to determine its value for a given set of system variables. Appropriate metrics and valid and reliable instruments to measure them are much easier to identify in science and engineering than in education, an obstacle that has limited engineering education research until fairly recently.

Research and Assessment Methods

Many engineering professors are aware of the minute paper and other classroom assessment techniques described by Angelo and Cross (1993) and regularly use these methods to improve their teaching. A smaller but growing cadre of faculty members has engaged in more formal research studies on the effectiveness of different approaches to course design and delivery.

The most commonly used assessment instruments in studies reported in the *Journal of Engineering Education* are student surveys and end-of-course ratings (Wankat, 1999). Surveys are easy to use and frequently satisfy reviewers of proposals and papers related to engineering education; however, results based entirely on them lack the credibility needed to persuade engineering professors to modify their teaching methods.

Most published studies in which the assessment has gone beyond surveys have involved comparisons of experimental and control group test scores and retention rates. Quantitative studies of this type are much more credible than survey-based studies to engineering faculty members, but there are several obstacles to their use. One is that few engineering classes have enough students to form experimental and control groups large enough to yield statistically significant results; another is that few engineering professors are familiar with the complexities and ethical issues involved in human subject research; and still another is that control group studies must be planned in advance, whereas many innovations in engineering education seem to develop more by natural growth and change than from preplanning.

Due in part to these difficulties, relatively few of the studies reported in the *Journal of Engineering Education* have used rigorous quantitative methods, and many of those that have done so suffer from methodological weaknesses. One notable exception is the body of research on cooperative learning. Many studies have shown that the more students work in cooperative learning groups the more they learn, the better they understand what they are learning, the easier it is for them to remember what they learn, and the better they feel about themselves, the class, and their classmates (see Johnson *et al.* 1998 a-c). Springer *et al.* (1999) meta-analyzed the research for college-level science, mathematics, engineering and technology and found significant effects on students' persistence and achievement in these fields and positive attitudes toward their education. Such studies are likely to be more persuasive in the engineering education community than any other type.

The qualitative research methods used widely in the social sciences are gradually percolating into the engineering education literature, although few engineering professors are familiar with them. Predominantly qualitative studies of retention in college science education performed by Tobias (1990) and Seymour and Hewitt (1999) have been extensively cited in the literature, and methods that involve content analysis of transcripts of student interactions have been used in several engineering research studies (e.g., Adams and Atman, 2000 and Haller, *et al.* 2000). This type of research will undoubtedly become more common in engineering as more faculty members discover that some of the skills specified by Engineering Criteria 2000 can be assessed most effectively using qualitative methods.

Assessing Educational Scholarship

Although assessing the scholarship of discovery in engineering is frequently an exercise in counting publications and grant dollars, most engineering professors are trained as researchers in their discipline and believe they know quality research when they see it. The situation is different for the scholarship of teaching and learning, which is not part of the education or experience of most engineering professors. Demonstrating that the scholarship of teaching and learning can be evaluated with just as much rigor as the scholarship of discovery will be an essential step in establishing it as an acceptable basis for advancement up the engineering faculty ladder.

Felder (2000) suggests that reviews of a faculty member's promotion dossier or award nomination package should focus the assessment of the scholarship of teaching and learning on answering the following questions:

1. *To what extent does the instructor's teaching qualify as a scholarly activity?* Boyer (1990) proposes mastery of the subject being taught, knowledge of effective instructional methods, and commitment to

continuing personal growth as a teacher as the criteria for scholarly teaching.

2. *How effective is the instructor's teaching?* How appropriate are the instructor's learning objectives and to what degree have students acquired the knowledge, skills, and values set forth in the objectives.

3. *How numerous and effective are the instructor's educational research and development efforts?* Glassick *et al.* (1997) suggest that the standards for evaluating educational innovation should be clarity of goals, adequacy of preparation, appropriateness of methods, significance of results, effectiveness of presentation, and depth of reflective critique.

The data that can be used to answer these questions fall into four categories:

- *archival data:* lists of courses developed and taught, representative instructional materials and student products, numbers of undergraduate and graduate students advised and faculty colleagues mentored, disciplinary and education-related conferences and workshops attended, articles and books and courseware published.

- *learning outcomes assessment data:* test results, evaluations of written and oral project reports and other student products, student self-assessments.

- *subjective evaluations by others:* student end-of-course ratings, retrospective student and alumni ratings, peer ratings, awards and recognition received, reference letters.

- *self-assessment data:* statement of teaching philosophy and goals, self-evaluation of progress toward achieving the goals.

Table 2 contains a matrix that may be used to design an educational scholarship assessment protocol (Felder 2000). The more types of data collected for a specific column of the matrix, the more valid the evaluation of that component of the scholarship of teaching and learning.

The Ultimate Challenge: Legitimizing the Scholarship of Teaching and Learning in the Faculty Reward System

In recent years, growing numbers of engineering schools have begun to regard teaching in a meaningful way in personnel decisions. Instructors whose teaching is judged inadequate can no longer be assured of winning tenure and promotion, even if they meet and exceed local standards for research achievement.

The playing field is by no means level for teaching and research, however. At most research universities, teaching quality and the scholarship of teaching and learning still count for considerably less than the scholarships of discovery, integration, and (to a lesser extent) application in determining progress up the faculty career ladder. A handful of research universities have granted promotions to full professor on the basis of their teaching, educational research, and textbook writing, but the bar for these promotions appears to be significantly higher than it is for professors with more conventional dossiers.

A second issue is the impact of the scholarship of teaching and learning on mainstream engineering education. Most engineering professors do not read the literature that demonstrates the advantages of student-centered instructional methods and continue to insist on exclusively lecturing. A related concern is the disconnect that sometimes occurs between teaching scholarship and teaching quality. Professors who carry out educational research but are not good teachers undermine efforts to elevate the status of the scholarship of teaching and learning in the academic reward system.

A third issue involves the relatively weak financial support base for the scholarship of teaching and learning. Examination of the 72 papers published in the 1999 *Journal of Engineering Education* reveals that 65% percent reported no financial support, 19% reported support from the National Science Foundation, 8% from the authors' universities, 6% from industry, 4% from foundations, and 3% from FIPSE. Six other sources of support were listed once, and some papers listed multiple sources of support.

The primary reason that disciplinary research has become the coin of the realm in engineering faculty advancement is the ready availability of funding for such research since the late 1950s. If faculty members wishing to engage in educational research are to have the same opportunities for career advancement as their counterparts engaged in disciplinary research, they must have the same opportunities to raise money for release time and fringe benefits, student support, equipment and supplies, and overhead costs. The National Science Foundation has taken the lead in providing such opportunities, with dramatic impact. Capitalizing on other existing sources of funding, notably foundations and industry, and developing new sources will be essential to the continuing growth of the scholarship of teaching and learning in engineering.

Finally, multidisciplinary collaboration between engineers and non-engineers is essential if the scholarship of teaching and learning in engineering is to attain a suitable level of professionalism. Many engineering professors understand this need. For example, 22% of the authors in the *Journal of Engineering Education* and 48% of the authors most frequently cited from 1993 to 1997 are not engineers (Wankat, 1999). Most of the major NSF grants in engineering education have included co-principal investigators from other disciplines, and all of the NSF engineering education coalitions have involved non-engineers in key positions.

What roles can a non-engineering professional play on a team working to improve engineering education? Engineers are not trained in ethnographic research methods, the construction of questionnaires, interpretation of videotape or audiotape transcripts, and other assessment methods. Professionals trained in these areas can have a major impact on educational research studies. Most engineering professors also have no formal education in pedagogy, developmental psychology, communication theory, and other areas that can impact engineering education. Professionals with backgrounds in these fields can help enormously in project planning, proposal preparation, and project management.

What roles could an engineering professor play on a team improving education in other fields? Engineers understand technology and can help in the development of instructional technology for all disciplines, including hardware and software to assist students with disabilities. They also can draw on funding sources to which other disciplines have not traditionally enjoyed access.

Multidisciplinary collaboration is not without its difficulties, however, as everyone who has tried it has discovered, and the difficulties can be particularly formidable when the collaborations are between engineers and social scientists, who frequently have different vocabularies, priorities, and conceptions of research. Learning to work together as an effective team under such circumstances is a challenge equal to any that have been described in the business administration and cooperative learning literatures, but the rewards for doing so successfully are equally great.

Conclusion

The scholarship of teaching and learning is starting to have an impact on engineering education but formidable barriers to its acceptance remain, the most critical of which are the reward structure in colleges of engineering and engineering professors' lack of pedagogical knowledge. There are grounds for cautious optimism, however. Some colleges are starting to change their reward structures to take scholarly teaching and the scholarship of teaching and learning into account, and a growing cadre of engineering professors with interest and knowledge of pedagogical issues in engineering education is emerging. It is not difficult to foresee the benefits to students, industry, and society that will surely result from a continuation of these trends.

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Table 1. Literature on Engineering Education

Journals

Chemical Engineering Education
IEEE Transactions on Education
Journal of Engineering Education
International Journal of Continuing Engineering Education
International Journal of Electrical Engineering Education
International Journal of Engineering Education
International Journal of Mechanical Engineering Education

Magazine

ASEE PRISM

Proceedings

Proceedings of ASEE Annual Conferences
Proceedings of Frontiers in Education Conferences

Books

Teaching Engineering (Wankat and Oreovicz 1993)
The New Professor's Handbook: A Guide to Teaching and Research in Engineering and Science (Davidson and Ambrose 1994)
Tomorrow's Professor: Preparing for Academic Careers in Science and Engineering (Reis 1997)

Table 2. Assessment of Teaching and Scholarship of Teaching

	Assessment of scholarship of teaching					
	Assessment of teaching					
	Subject Knowledge	Pedagogical Knowledge	Commitment to PersonalGrowth	Teaching Effectiveness	Innovation and Dissemination	Quality of Innovation
Statement of teaching philosophy		X	X			
List of courses taught and developed, representative instructional materials	X	X			X	
Representative student products				X		X
Learning outcomes assessment data				X		X
End-of-course student ratings for the past 2–3 years				X		X
Retrospective senior ratings	X	X		X		X
Alumni ratings	X	X		X		X
Peer ratings	X	X		X	X	X
Teaching seminars and conferences attended, books read, journals subscribed to		X	X			
Faculty colleagues mentored			X			
Self-evaluation	X	X	X	X	X	X
External references	X	X	X	X	X	X
Awards and other recognition				X		X
Presentations, invited seminars, and workshops on teaching given		X			X	
Published textbooks and courseware	X	X			X	X
Published papers and monographs	X	X			X	X
Proposals written and grants awarded		X			X	X

Row groups: Assessment of teaching (Statement of teaching philosophy through Presentations, invited seminars, and workshops on teaching given); Assessment of scholarship of teaching (all rows).