The Emergence of Engineering Education as a Scholarly Discipline

Phillip C. Wankat
School of Chemical Engineering, Purdue University

"It is essential that those selected to teach be trained properly for this function."[2]

Abstract
Changes in engineering education are part of a national trend to develop the scholarship of teaching and learning in all disciplines. As many engineering faculty have realized, content knowledge alone is not sufficient to be a good teacher. Pedagogical skills are required as well. Unfortunately, this need has been only partially met with workshops and summer programs instead of a systematic reorganization of graduate education. Recent developments such as changing ABET requirements and NSF education and CAREER grants have highlighted the importance of formal training in pedagogy. Teaching, learning, and the scholarship of teaching and learning are central to the emerging discipline of engineering education. All engineering professors can become effective and efficient teachers, assess student learning, and improve engineering education. And for professors interested in engineering education, this discipline will also provide a new career path.

A Short History
This short history is based on Grayson's[1] history of engineering education in the United States and Canada. Formal education in engineering in the United States started in 1802 at the United States Military Academy at West Point. The first civilian institution teaching engineering was the American Literary, Scientific and Military Academy (now Norwich University) closely followed by the Rensselaer Institute which awarded the first engineering degrees (in civil engineering) in 1835. Although these efforts preceded the organization of professional societies that started with the American Society of Civil Engineers in 1852, many of the early engineers in these societies were either self-trained or had served apprenticeships. At the end of the Civil War only about twenty engineering programs were operating in the United States. With the Morrill Land Grant act this number rapidly increased to seventy by 1872. Yet despite this increase, it was only gradually that a formal college education in engineering was required to become an engineer.

From the beginning, engineering educators were interested in improving engineering education. In 1893 the Society for the Promotion of Engineering Education (SPEE, which became ASEE in 1946) was formed at the World's Columbian Exposition in Chicago. The original publication was the *Proceedings* based on papers and the minutes of the board meeting at the annual meeting. SPEE started the *Bulletin* as a monthly magazine in 1910 and changed the name six years later to *Engineering Education.* When this journal was merged with the *Proceedings* in 1924, it became the *Journal of Engineering Education,* which later shortened the name back to *Engineering Education.* This magazine continued as a mix of scholarly and popular articles until 1991 when publication temporarily ceased. *ASEE PRISM* was started that year and the new *Journal of Engineering Education (JEE)* was started in January 1993. Separate Proceedings were again published starting in the 1970's: first from the Frontiers in Education conferences, then from the College Industry Education Conference, and finally from the ASEE Annual meeting.

Improving teaching was a continuing concern of SPEE and ASEE. Calls to improve the pedagogical training of engineering professors were heard as early as 1901, and formal training was started during an industrial summer school in 1911. More extensive summer programs were held from 1927 to 1933 which "concentrated on both the content of the subject and on methods of organizing and teaching it." (reference 1, p. 138). The Hammond report in 1944 called for a more systematic development of teaching skills. The influential Grinter report called for postgraduate training in pedagogy: "it is essential that those selected to teach be trained properly for this function."[2] Since 1927 a number of summer programs on teaching improvement, either for specific disciplines or in conjunction with the annual meeting, have been held. These programs continue with popular regional and National Effective Teaching Institutes, the latter held in conjunction with the ASEE annual meeting. In 1983 the ASEE Quality in Engineering Education Project again called for more training of faculty in educational methods.

Students suffer when professors do not learn to teach until after their first classes. Workshops are also always constrained by the time available. A better approach is to learn to teach in graduate school by taking a course in the College of Engineering on teaching methods. As early as 1972 Professor Jim Stice pioneered this approach at the University of Texas at Austin[3]; unfortunately, few universities followed his lead.

Recent Developments in Educational Scholarship

The watershed year in the national development of the scholarship of teaching and learning is clearly 1990 when Ernest Boyer's report, *Scholarship Reconsidered*[4], was published. Boyer called for four scholarships: *discovery, application, integration*, and *teaching.* In engineering the scholarships of *discovery* and *application* have long been major parts of technical research. The scholarship of *integration*, which involves multidisciplinary technical research and a search for the meaning of the research in a broad context, has become more important in recent years. The groundbreaking aspect of Boyer's report involved his definition of the scholarship of *teaching*, which has since been extended to the scholarship of *teaching and learning*[5]. This scholarship, which is not teaching but is a scholarly study to improve teaching and learning, is starting to have a major impact in a number of disciplines including engineering[6].

The developments since 1990 have shown why every discipline taught in college needs to be concerned with the scholarship of teaching and learning. Every discipline has *pedagogical content knowledge* that is concerned with the question of how to best teach the content of the discipline. People who do not understand the discipline's content cannot know the best way to teach that content. Since all disciplines contain a certain amount of chauvinism, educational scholarship and teaching workshops from professors within the discipline are more believable than from professors from other disciplines. For example, a "How-to-teach engineering" course or workshop will be best taught by an engineering professor perhaps in conjunction with a colleague from another discipline[3]. The number of such engineering education courses has increased, but they are still far from being common. Professors knowledgeable in both the discipline and in pedagogy also serve as gate-keepers to transfer educational concepts from other disciplines and apply it to engineering education.

A number of additional factors have influenced the scholarship of teaching and learning in engineering. First, NSF support for educational grants has made educational research both more lucrative and more prestigious. One result has been an improvement in the quality of educational research in engineering. NSF continues to push researchers and referees to consider the broader impact of technical research including interactions with K-12 and efforts to increase diversity. Otherwise meritorious technical proposals may be denied funding because of weaknesses in these areas. NSF CAREER awards require applicants to address their teaching and educational plans. Since most new professors are well-prepared for the technical research they propose, the deciding factor in funding CAREER proposals is often the educational portion.

A second major factor involves changes in ABET accreditation procedures[7]. The switch from "bean counting" to an outcomes based approach has made assessment an important topic in engineering colleges. The impending application of continuous improvement during ABET's second visit to an institution under ABET 2000 criteria may have an even more profound effect.

Third, changes in *JEE* reflect the changing times. When *JEE* was restarted in 1993, it was as a scholarly journal that would publish a broad range of scholarly articles[8]. After ten years following this course, *JEE* was refocused into an archival journal of engineering education research[9]. The result appears to be an almost exclusive focus on the scholarship of teaching and learning, and tighter quality control compared to the previous ten years[10]. Some articles that were previously acceptable are not acceptable under the new format, thus causing a certain amount of angst in former contributors.

Fourth, there has been an increased interest in teaching. Pressure from students, parents and legislatures has been at least partly responsible for this increased interest. Most research universities now require good or at least acceptable teaching for promotion and tenure[11]. This has led to an increase in courses and workshops on how to teach engineering[3], and the publication of the book *Teaching Engineering*[12], which was written with NSF support.

Finally, the environment for new engineering faculty has changed. New faculty are more likely to have done post-doctoral study and less likely to have significant industrial experience. Most position announcements delineate an expectation that a significant research program will be developed. Start-up costs are increasing at an exponential rate (greater than 15%/year in chemical engineering), which has also increased expectations for a rapid research start. The emphasis of ranking schemes on quantifiable measures also increases the pressure to be productive. Although many institutions give a reduced or zero teaching load the first semester, new professors will need to start developing courses shortly after arriving. In addition, some universities are asking assistant professors to leave after the first three years of the six year probationary period. All of these changes have led to an increased need to "hit the ground running."

Engineering Education for All Professors

What can the emerging discipline of engineering education do to help all faculty in engineering? First, all prospective faculty will benefit from taking a course on “How-to-teach engineering” as a graduate student[3,11,12]. The best approach would be to be a teaching assistant, take a teaching course as a graduate student, teach in a supervised internship program, and then after teaching a few courses as an assistant professor attend teaching workshops. Courses in graduate school can provide a depth that is not possible in workshops. But certain aspects of teaching such as discipline, preventing cheating and student motivation are appreciated and understood much better after one has taught a few times. The mistake that many graduate students and new faculty make is to assume that these teaching courses and workshops are only for faculty whose major interest is teaching. The goals of most teaching programs are to produce teachers who will be good, which will benefit all faculty.

New faculty will be much more productive in their first years if they know something about teaching before they start. On-the-job training to learn how to teach is an extremely inefficient process. New faculty whose first experience teaching is during their first faculty position will find that they need to spend enormous amounts of time learning to teach effectively at the same time they need extra time to start their research programs[11]. Formal courses and to a lesser extent teaching workshops can also provide new faculty with the language, educational background, ideas and references to effectively compete in the educational part of NSF CAREER proposals.

Implementation of this recommendation will require some restructuring of graduate curricula and of attitudes of research advisers. Obviously, a course on teaching engineering will have to be instituted. Since most of the pedagogy for teaching engineering is generic to all engineering disciplines[12], this can be a college-wide course. Then, research advisers will have to realize that it is in the best interests of their graduate and postdoctoral students to take such a course. Since most research advisers have likely never taken such a course, they may have trouble seeing the need. Perhaps the most compelling argument is the increased educational professionalism that will be required of their graduates when they compete for CAREER and other NSF grants.

The new discipline of engineering education can help departments with accreditation issues. ABET has made assessment an important topic in engineering education. To satisfy ABET’s call for continuous improvement, engineering departments will have to incorporate more rigorous assessment techniques to determine what students are learning. To a large extent the low hanging fruit (surveys) has been picked. Engineering professors with an expertise in education can help transfer assessment approaches from other disciplines and help develop new methods specifically for engineering education. For example, assessment of design courses will have to be developed by engineering educators. Although help is available[13], implementation is never easy.

If assessment indicates there are problems, continuous improvement will require changes in curriculum, teaching and learning styles. At many schools the low hanging fruit for improvement (informal cooperative groups for active learning) has been picked although active learning methods are still underutilized. Professors who are knowledgeable in the discipline of engineering education can help their colleagues adapt and develop new teaching/learning methods[11,12,14] to address the problems identified by assessment. Fortunately, some of the effective teaching methods are also quite efficient and require less professorial time[11]. An example is requiring students to develop homework or test questions and then selecting some of these questions for use.

Another area that can benefit enormously from engineering education research and development is the proper evaluation of teaching. In the absence of better evaluation tools, the quality of teaching is usually determined from student evaluations. Well constructed student evaluations are reliable and valid, that is, they correlate with student learning as measured by test scores[12]. However, the best correlation coefficients are in the range of $r = 0.5$. Thus, student evaluations explain only 25 percent of the variance in student performance. Clearly, student evaluations miss many aspects of good teaching and include extraneous factors such as the professor's enthusiasm. Student evaluations are the best approach for determining student attitudes, but students are not able to evaluate whether they were taught the right material. Engineering professors need to learn about the strengths and weaknesses of student evaluations. Then, different evaluation methods such as content evaluation by practicing engineers are needed to supplement student evaluations.

As they grow older, it is not unusual for faculty to become less interested in technical research and more interested in teaching and working with students. This awakening interest in educational issues often motivates faculty to attend teaching workshops, become involved in educational research, join ASEE, and start reading the educational literature such as *JEE* articles. The presence of a vibrant community of engineering education experts can welcome these professors and help them start on their new agenda. These professors may even start writing educational proposals, bring in grant money, and make their administrators happy after all. Some older professors become interested in service, faculty governance and administration, but that tangent is covered elsewhere[11].

Careers in the Discipline of Engineering Education

The engineering education system in the United States needs some experts on engineering education who focus all or part of their research and development efforts on education. This research/development could focus on assessment of student learning, development of new teaching methods including methods using technology, improving the evaluation of teaching, development of methods to increase the recruitment and retention of underserved populations, improving academic advising procedures, developing service learning, improving the educational value of co-op and internships, developing entrepreneurship opportunities, and so forth. Perusal of recent issues of *JEE* and ASEE *Proceedings* will show many other possibilities.

The "traditional" path to becoming an engineering education expert has been to start with a standard tenure track appointment as an assistant professor in a disciplinary department. Tenure and promotion are earned through disciplinary research and good teaching. Some time later the interest and involvement in teaching and educational issues blossoms. Because of the time required for any serious research/development effort, this blossoming of interest in education will often occur when interest in technical research subsides. Although faced with the problem of learning a new research area without formal training, this professor eventually finds him or herself an educational expert within a disciplinary department. For certain types of educational endeavors such as development of disciplinary assessment techniques or writing textbooks a disciplinary department is an appropriate home. If the professor combines educational interests with good teaching and service (particularly a willingness to take on ABET accreditation) and is reasonably diplomatic about how other professors should teach, he or she can be a highly appreciated, though perhaps not highly paid, member of the department.

On the other hand, the outcome may not be this rosy. The educational expert may feel unappreciated and not have anyone to talk to in the department (hence the importance of an informal campus network of faculty interested in engineering education). Other faculty in the department may resent that this professor is not pulling his or her share of the load, that is, not bringing in research money. There may be less respect for educational research than for technical research even though NSF curriculum development money is very difficult to obtain and *JEE* now has more stringent publication requirements than many technical journals. With this potential downside, why would faculty choose this route? Frankly, most faculty who follow this route don't choose--they feel compelled to work on educational issues.

The "pioneering" path is to start as an assistant professor with a tenure track appointment, probably in a disciplinary department, as an engineering educator. These professors expect to be judged by their educational scholarship and their teaching. The educational background for these professors would ideally include engineering education research during their Ph.D.s. In addition to standard graduate courses in engineering, some courses in education such as pedagogical methods, educational psychology, assessment and qualitative research methods would be appropriate.

Pioneers take risks. Currently, the job market as well as the promotion path is uncertain. At many institutions promotion committees will need to change to accommodate engineering educators. Respect from other engineering professors will not be automatic and will have to be earned. Although being a good engineering teacher and publishing will help one earn respect, the current gold standard is to bring in research money. The availability of educational research money from NSF has had and will continue to have a major impact on the development of respect for engineering education research. Unfortunately, most engineering promotion committees have few if any professors who have done significant educational research and thus are capable of evaluating its quality.

Purdue University and VPISU have both announced they are developing a department of engineering education[15]. Where will the pioneering graduates find jobs? Graduates with master's degrees should have a good market as professors at community colleges or lecturers or staff members at four year colleges and universities. Graduates with Ph.D.s can add professorial positions at four year colleges and universities to this list. These departments may eventually follow the lead of departments of biology education, chemistry education, mathematics education, and physics education and also produce teachers for K-12. In the long term, placing engineering teachers in the K-12 system may be the most important contribution of the discipline of engineering education.

Pioneers will benefit if others follow their path. I predict that within ten to fifteen years many pioneers will be the leaders of the vibrant new discipline of Engineering Education.

Bibliography

1. Grayson, L. P., *The Making of an Engineer,* John Wiley & Sons, New York, 1993.
2. Grinter, L. E., (chairman), "Report of the ASEE Committee on Evaluation of Engineering Education," *J. Engr. Educ.,* (Sept 25, 1955). Reprinted in *J. Engr. Educ., 83* (1) 74-94 (1993).
3. Wankat, P. C., "Educating Engineering Professors in Education," *J. Engr. Educ., 88*, 471-475 (1999).
4. Boyer, E. L., *Scholarship Reconsidered,* The Carnegie Foundation for the Advancement of Teaching, Princeton, NJ, 1990.
5. Barr, R. B. and Tagg, J., "From Teaching to Learning – A New Paradigm for Undergraduate Education," *Change, 27* (6) 13-25 (1995).
6. Huber, M. T. and Morreale, S. P. (Eds.), *Disciplinary Styles in the Scholarship of Teaching and Learning,* American Association for Higher Education, Washington, D.C., 2002.
7. "Engineering Criteria 2000: Criteria for Accrediting Programs in Engineering in the United States," Accreditation Board for Engineering and Technology, Inc., Baltimore, MD (1997).
8. "Guide for Authors," *J. Engr. Educ., 82* (1), inside back cover (1993).
9. Lohmann, J. R., "The Editor's Page," *J. Engr. Educ., 92* (1), 1 (2003).
10. Wankat, P. C., "Analysis of the First Ten Years of the *Journal of Engineering Education, J. Engr. Educ.* (in press, Jan 2004).
11. Wankat, P. C., *The Effective, Efficient Professor,* Allyn & Bacon, Boston, 2002.
12. Wankat, P.C. and Oreovicz, F.S., *Teaching Engineering*, McGraw-Hill, NY, 1993. Free at <https://Engineering.Purdue.edu/ChE/News_and_Events/Publications/Teaching_Engineering/>.
13. Rogers, G. M. and Sando, J. K., *Stepping Ahead: An Assessment Plan Development Guide*, Rose-Hulman Institute of Technology, Terre Haute, IN, 1996.
14. Light, R. J., *Making the Most of College. Students Speak Their Minds,* Harvard University Press, Cambridge, MA, 2001.
15. Katehi, L., Banks, K., Diefes-Dux, H., Follman, D., Gaunt, J., Hahgighi, K., Imbrie, P. K., Montgomery, R., Oakes, W., and Wankat, P., "Development of Graduate Programs in Engineering Education," *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition,* (in press).

Biography: PHILLIP C. WANKAT
Phil Wankat is the Clifton L. Lovell Distinguished Professor of Chemical Engineering at Purdue University. He earned his BSChE from Purdue, his Ph.D. from Princeton University and an MSED from Purdue University. His technical research is in separation processes and he is interested in improving teaching and learning in engineering education. E-mail: wankat@ecn.purdue.edu.