AC 2009-852: THE ROLE OF CHEMICAL ENGINEERING IN ENGINEERING EDUCATION RESEARCH

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The Role of Chemical Engineering in Engineering Education Research

Abstract
Chemical engineers have historically played a very significant role in advancing engineering education; however, since research in engineering education has become much more rigorous in the last ten years, it is not obvious that chemical engineers will maintain this significant role. There are many specific questions within the five identified engineering education research areas (Epistemologies, Learning Mechanisms, Learning Systems, Diversity & Inclusiveness, and Assessment) that can be best explored by chemical engineering professors. To maintain a leadership role in engineering education research some chemical engineering departments will have to make engineering education a research specialty and offer Ph.D. degrees based on research in engineering education. This will require that a few motivated chemical engineering professors retool their research from a technical specialty to engineering education.

Introduction

Despite being a relatively small engineering discipline and despite the conservatism of ChE departments, chemical engineers have been leaders in the push for engineering education reform and in engineering education research. Examples of chemical engineering leadership in pedagogy include the Chemical Engineering Division of ASEE Summer School that meets every five years, the Division's publication of the journal *Chemical Engineering Education,* and leadership in teaching professors how-to-teach. Leadership in educational research has included the development of the guided design method, introducing Problem Based Learning into engineering, laboratory improvements and hands-on learning including distance operation of experiments, and the championing of cooperative group learning. One possible reason that chemical engineers have had influence greater than their numbers is, unlike most engineers, they are trained to think of processes, and teaching/learning are processes not products.

Research in engineering education has recently become much more rigorous and a new discipline of engineering education is developing. This paper will explore the roles of ChE professors and ChE departments for chemical engineering to retain its leadership role in engineering education research. What research questions should be explored? How can ChE professors who are not trained to do rigorous educational research develop their expertise so that they can successfully compete? Should ChE departments offer Ph.D. degrees for research in engineering education? What types of jobs will be available for graduates whose Ph.D. research is in engineering education? How should engineering education research be disseminated so that it is adopted as part of teaching practice?

Background: Engineering Education Research

Significant changes are occurring in research in engineering education. Signs of these changes include the *Journal of Engineering Education's (JEE)* changing publication requirements[1-3], the development by NAE of the Center for the Advancement of Scholarship on Engineering Education (CASEE)[4] which developed the engineering education research portal AREE for dissemination of engineering education research, the increased availability of funds for engineering education research from NSF but with a stricter review process, development of a national research agenda for engineering education[5], the development of engineering education research centers[4], the development of departments of Engineering Education, Engineering and Science Education, and Engineering and Technology Education department[6]; and a small but increasing number of chemical engineering departments that allow students to do their Ph.D. research on engineering education[6]. These and other significant changes in the structure of engineering and the development of a new field or discipline of engineering education are reviewed in detail elsewhere[6-8].

Early engineering education research papers were seldom rigorous and often did not contain any data or references[9]. Before 1990 engineering was typical – with a few exceptions disciplinary educational research was not held to a high standard. The rigor of disciplinary educational research started to increase after Boyer's[10] 1990 publication calling for a scholarship of teaching. Engineering education research started to change after NSF launched the Engineering Education Coalitions in 1990[7] and change continued in 1993 when the *Journal of Engineering Education* increased the standards for scholarship[1]. The 1993 *JEE* requirements represent the *old paradigm* for quality in engineering education research. This quality level was accessible to all engineering professors since it could be met by doing classroom research[11] that included student course evaluations and/or surveys plus cited appropriate references. Many of the engineering professors publishing research papers at this quality level were doing educational research as a hobby[8]. In 2003[2] and again in 2008[3] change in engineering education research accelerated when *JEE* made its review requirements more stringent. This *new paradigm* of quality, now expected by *JEE* and NSF, requires[3, 12-14] that engineering education research have hypotheses on significant questions stated in advance and then tested during the research, have a thorough literature review, ground the research with a theory of learning or human development, include an appropriate mix of quantitative and qualitative research tools, and obtain approval or an exemption in advance from the Institutional Review Board (IRB) if students are involved.

Research Areas in Chemical Engineering Education

The NSF sponsored Engineering Education Research Colloquies[5] developed a national agenda for research in engineering education. These areas are:

> "**Area 1-Engineering Epistemologies**: *Research on what constitutes engineering thinking and knowledge within social contexts now and into the future."*
> **"Area 2-Engineering Learning Mechanisms**: *Research on engineering learners' developing knowledge and competencies in context."*
> **"Area 3-Engineering Learning Systems**: *Research on the instructional culture, institutional infrastructure, and epistemology of engineering educators."*
> **"Area 4-Engineering Diversity and Inclusiveness**: *Research on how diverse human talents contribute solutions to the social and global challenges and relevance of our profession."*
> **"Area 5-Engineering Assessment**: *Research on, and the development of, assessment methods, instruments, and metrics to inform engineering education practice and learning."*

These five areas are quite broad in scope and many research projects that are of interest to many engineering fields are included. Although the five areas do not and were not expected to encompass all areas of research of interest, they are flexible enough to incorporate a variety of research questions. For example, research questions about student motivation can be framed within areas 2 through 5.

Each area can easily include a number of research questions that are very specific to chemical engineering education. Examples of chemical engineering specific research topics in each of the five areas are:

Area 1- Epistemologies.
What skills and knowledge will chemical engineers need to be successful 2-4 years, 10-12 years, and 25-30 years after graduation?
What roles will chemical engineers take in different industries a specified number of years from now?
Is chemical engineering education for industry or education for a productive life?
If chemical engineering is education for industry, how do we change the education process to ensure more graduates have careers as chemical engineers?

Area 2- Learning Mechanisms.
How do students acquire, comprehend, and synthesize chemical engineering specific knowledge such as mass and energy balances, chemical reactor design or separations?
What barriers impede student understanding of energy balances of reactive mixtures?
How do chemical engineering students develop an identity as a chemical engineer?
What external activities such as clubs, part-time jobs, or internships will help chemical engineering students learn?
What are the best ways for practicing chemical engineers to learn new areas needed in their jobs?

Area 3- Learning Systems.
What teaching methods are best for teaching a diverse student body specific chemical engineering material such as separation processes?
What is the best way to teach chemical engineering design?
How should chemical engineering laboratories be structured to maximize student learning?
How do we allocate the resources in a chemical engineering department to optimize the learning of undergraduate and graduate students?
What is the best culture in a chemical engineering department to help students learn?
How much help is optimum to maximize the learning of chemical engineering students?
How do we do continuous improvement of a chemical engineering program?

Area 4-Diversity and Inclusiveness.
What factors have made chemical engineering relatively more attractive to women than other areas of engineering?
What can we do to increase the attractiveness of chemical engineering to women?
What needs to be done to retain more women in the chemical engineering profession after graduation?
How do we attract more women into the ranks of chemical engineering faculty?

What requirements expected of chemical engineering faculty are inadvertently less friendly to female faculty?
What can we do to increase the attractiveness of chemical engineering to underrepresented minorities?
What needs to be done to retain more underrepresented minorities in the chemical engineering profession after graduation?
How do we attract more underrepresented minorities into the ranks of chemical engineering faculty?
What requirements expected of chemical engineering faculty are inadvertently less friendly to underrepresented minority faculty?

Area 5- Assessment.
How do we assess the motivation of chemical engineering students?
How do we help chemical engineers to learn to self-assess so that they can take charge of their own learning?
How can we assess for student comprehension, not just plug-and-chug problem solving, in chemical engineering specific topics such as mass and energy balances?
What are the best assessment methods for each chemical engineering program outcome?
How do we convince chemical engineering programs to use best assessment methods?
How do we convince chemical engineering ABET visitors to accept best assessment methods?

Although many of these questions can be asked of other engineering programs by substituting that program name instead of chemical engineering (e.g., "What skills and knowledge will mechanical or electrical engineers need to be successful 2-4 years, 10-12 years, and 25-30 years after graduation?"), we need specific answers for chemical engineers. And only chemical engineers are motivated enough to find the answers to these specific questions.

Most chemical engineering professors are unfamiliar with these research areas and research questions. Fortunately, understanding the specific research questions, which is relatively easy, will lead to an understanding of the five research areas.

Conducting Rigorous Engineering Education Research

The vast majority of engineering professors are unfamiliar with the research tools required for rigorous educational research, and they may not realize that their educational research is not rigorous[15]. They are unfamiliar with grounding their research in a theory of learning or human development. Although some ChE professors are very knowledgeable about statistical methods, most are less familiar with educational statistics. Few ChE professors are familiar with qualitative methods, and their first reaction when reading about qualitative methods may be distrust. Yet, many of the questions listed above fit better with constructivist inquiry, not with quantitative methods. For example, in area 1 the question "Is chemical engineering education for industry or education for a productive life?" requires an analysis of what a "productive life" is, which is a constructivist question that will require qualitative research methods. As another example consider area 5, assessment. Although ChE departments do assessments for ABET accreditation, these assessments are seldom rigorous enough for the new quality paradigm of educational research. Even as basic a question as, "What are the best assessment methods for each chemical engineering program outcome?" really requires qualitative research methods for the ABET professional outcomes 3d, 3f to 3j. Without constructivist inquiry it is not possible to define and assess outcomes such as "an ability to function on multidisciplinary teams" (3d) since there is no standard definition or metric of "function." Unfortunately, learning educational research tools is considerably more difficult than understanding appropriate educational research questions.

Although there are examples of ChE faculty who have been successful in retooling to do high quality engineering education research (e.g., Rich Felder, Ron Miller, and Mike Prince), ChE faculty who are retooling to do educational research will also be competing with faculty who received their graduate training in departments of Education or Engineering Education[6]. Perhaps the easiest approach to start doing rigorous engineering education research is to find a collaborator[16]. The acceptance rate of papers submitted to the *Journal of Engineering Education* is ten times higher if one of the authors is a social scientist than when all authors are engineers[16]. Because most engineering professors are not trained to do rigorous educational research, NSF has sponsored workshops to help interested professors start learning how to do rigorous educational research[14, 17]. These workshops also emphasize collaborations. The Chemical Engineering Division (ChED) of ASEE could play an important role by offering one thread on rigorous engineering education research at ChED Summer Schools. By working with an educational expert, reading about scientific research methods in education[12, 13], attending a workshop on rigorous engineering education research, studying articles in *JEE* and other journals, and perhaps taking education courses on their own campuses, engineering professors can reach a level where they can win NSF grants and publish their engineering educational research in the highest quality engineering education journals.

To ensure that chemical engineering continues to retain our leadership role in engineering education, some chemical engineering professors and departments will have to decide to make chemical engineering education a research specialty that is equivalent to bioengineering, catalysis, control, transport and other specialties[6]. If engineering education is to be an equal research specialty, there must be acceptance of graduate students in this area. A scattering of chemical engineering departments have awarded Ph.D. degrees to students who did engineering education research. Unfortunately, if the members of the Ph.D. research committees are not familiar with rigorous engineering education research, they may set the requirements for rigor too low, not require students to take appropriate research methods courses in education, and the resulting research may be conducted at the level of the old paradigm[6]. These graduates will be unprepared to compete at the level of the new paradigm. At least initially, either co-advisors with appropriate training in educational research or an interdisciplinary Ph.D. program in engineering education will be required to provide quality control.

Schools instituting engineering education as a research specialty will need to include engineering education research grants and papers in their promotion and tenure decisions, and these contributions must not be undervalued compared to technical research. Hopefully, these schools will also reward the other scholarships outlined by Boyer[10] – the scholarships of application, integration and scholarly teaching – even when these scholarships are applied to education.

There is a natural concern about what jobs will be available for graduates of a Ph.D. program that involved research in engineering education. Since these graduates have to take the required ChE courses and pass the ChE qualifying examination, they will be well qualified to teach and collaborate with other ChE professors. ChE departments at undergraduate institutions will be interested in hiring these graduates because their interest in teaching and their educational research specialty fits in very well with the school's mission. Some ChE departments at research institutions will also be interested in hiring a graduate as an educational expert to develop a research specialty in chemical engineering education. These graduates will also be knowledgeable about assessment and will probably be willing to shoulder the duties of preparing for ABET visits. Graduates will also be attractive candidates for positions in first-year engineering programs, at community colleges, at engineering teaching centers, as the educational leader in engineering research centers, and for K-12 outreach.

Another reason that some chemical engineering professors need to become involved in educational research is that if we don't do this research then others who do not understand chemical engineering will step into the vacuum, write the proposals, collect the NSF money, and do the research. Research done without an understanding of the context can easily miss the key research questions or use research tools inappropriately. For example, qualitative research methods often have a philosophical basis. This philosophical basis, which was based on a different educational context, needs to be analyzed in the context of engineering to determine if it is appropriate. Without this analysis of context, qualitative research has been published that cannot be generalized and that is based on questionable philosophical underpinnings. Spotting these subtle but critical errors requires reviewers who have expertise in both engineering and educational research methods. There is also the possibility that some social scientists will see publishing in the engineering education literature as the route to "a quick and easy publication."[16] To prevent inappropriate carpet-bagging the engineering education community needs to ensure that research is high quality educationally and fits the context of engineering.

Dissemination

How should chemical engineering education research be disseminated so that it is adopted as part of teaching practice? Without adoption in teaching practice, engineering education research has the danger of becoming an irrelevant "silo" with researchers talking only to each other and with no impact on the practice of engineering education. Several researchers and commentators appear to have the belief that if the research is compelling enough then other engineering professors will automatically see that they need to change what they do in their courses and change will be automatic[5, 18]. I am one of the other commentators[6, 19-21] who are less optimistic and note that there needs to be a much tighter coupling between researchers and practitioners to have impact on engineering students.

The problem that I expect will occur in disseminating engineering education research can be illustrated by progress in teaching engineering professors how to teach. Courses to teach Ph.D. students and faculty have been available for a number of years[22, 23], a textbook is available free[24], and the courses and workshops are known to be effective[25], yet most faculty continue to lecture and are unaware of other teaching methods and the available research. Perhaps the most effective program for focusing professors on education has been the NSF CAREER program – Money talks! The teaching portion of CAREER proposals is often characterized by significant energy, creative ideas, and amazing naiveté. A ramping up of the requirements for the teaching/learning part of NSF CAREER awards to require more rigorous educational understanding, perhaps at the level of one course on how to teach[22-25] would have a tremendous effect on the educational capability of new professors. It would also be helpful if NSF strongly encouraged dissemination of the teaching results at ASEE or AIChE meetings or through other suitable venues. Engineering faculty have received CAREER awards for proposals focused on engineering educational research.

How can we disseminate engineering education research results to drive changes in the US engineering education system? Research is not compelling if professors don't read the articles, and unfortunately, engineering professors often find that the research articles in *JEE* are difficult to understand. Because an understanding of the basics is necessary to understand research articles, encouraging Ph.D. students to find and take a course on teaching/learning would be a good first step in disseminating engineering education research. Ideally, Ph.D. students and post-doctoral researchers would be involved as partners with the faculty in both research and teaching. Integration of these activities could lead to Ph.D. graduates naturally having an understanding and appreciation for engineering education research.

Professors who did not have an educational background can obtain the background to understand educational theories and research methods through workshops, books[10-13, 24] and journals. *Chemical Engineering Education (CEE)* and the new applications-based ASEE electronic journal *Advances in Engineering Education*[26] can help provide this understanding.

CEE is a journal for *all* chemical engineering faculty. Thus, CEE publishes rigorous research papers, and expository and application papers about curriculum and course improvements, hands-on activities, and classroom-research[11] that, although not as rigorous, will be expected to be scholarly and satisfy the old paradigm for quality. These papers are often written by ChE professors whose main scholarly activities are in technical research, but who occasionally write an educational paper as a "hobby." Retaining the educational publishing efforts of these professors is critical. It would be a tragedy if an unintended consequence of developing more rigorous engineering educational research was that these interested professors could not publish papers on improving engineering education.

Recommendations

In order for Chemical Engineering to retain its leadership role in engineering education research, the following steps are recommended:

1. Develop chemical engineering specific research questions that fit into the national agenda for research in engineering education.
2. Develop a research specialty in chemical engineering education in some ChE departments. This research specialty needs to be considered as an equal partner with other research specialties.
3. Encourage interested ChE professors to retool to become engineering education experts.
4. ChED should offer a thread on rigorous engineering education research at Summer Schools.

5. Develop methods to teach ChE faculty the background required to understand engineering education research and encourage use of this research in courses. Ph.D. students, post-docs, and new faculty are probably the most attentive initial audience.
6. NSF should explore requiring more rigorous educational understanding and more dissemination of the teaching component in engineering CAREER proposals.

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