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Making the Policy Case for Engineering Education Research

Abstract

As an emerging field, engineering education research is slowly acquiring the characteristics of a true discipline. However, as is true for any research field, it risks asphyxiation unless adequate intellectual, human, and financial resources are made available to support knowledge generation, graduate education, and community building activities. This paper defines engineering education research, summarizes its development and early growth within the US, gives indications of international progress, and details those actions necessary by various stakeholders of engineering education research to build the policy case for our field within the academic, government, non-profit, and corporate sectors.

Engineering Education Research

Definition

Recent decades have seen increasing levels of research on collegiate education within scientific disciplines by scientists themselves, including by those in physics[1], chemistry[2], biology[3], mathematics[4,5], computer science[6], and the geosciences[7]. Such research might best be characterized as application-driven basic research occurring in "Pasteur's Quadrant"[8]. Driven by overarching questions such as — Can we better understand student learning of discipline *x*? — this type of research lays the foundation for more effective promotion of learning. These discipline-specific research findings hold the promise of encouraging college and university faculty members to bring the same rigor to classroom instruction that they currently employ in their scientific and technical research programs.

The case for discipline-based education research has been eloquently made by McDermott and Redish[9]:

> *Physics education research differs from traditional education research in that the emphasis is not on educational theory or methodology in the general sense, but rather on student understanding of physics. Such research requires an in-depth knowledge of the subject as well as access to students, which means that it can usually only be carried out by physicists working in physics departments. The findings form a rich resource that provides insights into how students learn physics. When teachers apply this information and document the results for others to use, cumulative improvement in instruction is possible.*

Broadly, discipline-based education research seeks to marry deep knowledge of the discipline with similarly deep knowledge of learning and pedagogy. More specifically, within the engineering community, the ultimate aims of such research include the creation of education programs that attract more, and more diverse, students to the study of engineering, retain more of the students who are enrolled, deepen learning of engineering concepts by students, broaden students' appreciation for the role of engineering in meeting the needs of a global society, and better prepare students for further study or professional practice. Engineering education research looks at all relevant aspects of systems of engineering education (e.g., who learns, what they learn, how they learn, how learning is facilitated or impeded, who facilitates learning, how they facilitate learning, what technological or interpersonal structures are used in learning, interactions of learners and learning facilitators, why a given topic is deemed important to learn, and the internal and external influences on learning systems including the goals of various stakeholders). An example of engineering education research applied to student retention is given by Fortenberry et al.[10].

We believe U.S. engineering education practice could benefit from the pursuit of engineering education research and the careful application research findings. For example, the statistics on the drop-out rates of engineering programs indicate there is room for improvement in current practice. On average, 40% of undergraduate students nationally leave engineering before graduation, with some schools reporting losses of up to 70%. Although definitive national numbers are not available, the data from individual engineering schools indicate that losses are particularly great among students from backgrounds underrepresented in engineering, with up to 70% of women, 70% of Latino students, and 50% of African-American and Native-American students dropping out of engineering before graduation[11]. Furthermore, the literature tells us that academic difficulty is not why they are leaving[12], and that other factors to consider include student's backgrounds, college administrative issues, academic and social integration, attitude and motivation, and fit within an institution[13]. We note that all of the relevant factors except a student's background are amenable to institutional intervention and improvement. Therefore, the high levels of engineering attrition raise concerns about the structure, content, and delivery of engineering education. The high attrition rates also raise questions about the ability of engineering schools to supply, efficiently, large numbers of graduates well prepared to enter the engineering workforce as well as to enter the broad array of other professions that benefit from employees possessing an undergraduate engineering education.

Development of a Research Community

The past 10-15 years have seen significant growth in the field of engineering education research. The 1990s saw the opening of numerous campus-based centers for research on engineering education. These include the Leonhard Center for the Enhancement of Engineering Education at Penn State founded in 1990 and the Center for Engineering Learning and Teaching at the University of Washington founded in 1998. These and other centers, along with engineering schools that are implementing innovative educational programs, are focusing on important aspects of engineering education scholarship ranging from foundational research to innovative approaches to curriculum, learning, teaching and assessment.

In 2001, the National Science Foundation initiated support for higher education-focused Centers for Learning and Teaching (CLTs). There are currently three CLTs specifically concerned with higher education, two of which — The Center for the Advancement of Engineering Education[14]], and the National Center for Engineering and Technology Education[15] — are specifically focused on engineering and technology education.

In 2002, the National Academy of Engineering opened the Center for the Advancement of Scholarship on Engineering Education[16]. CASEE represents a collaborative effort to improve the alignment of the knowledge and skills possessed by future and current engineers with the knowledge and skills sought by various stakeholders of engineering education. This effort is pursued through programs for engineering education research and innovation as well as activities to translate promising practices into wide use within the engineering community.

The opening of Departments of Engineering Education, first at Purdue University, and followed quickly thereafter by Virginia Tech, occurred in 2004. In 2005, a Department of Engineering and Technology Education was established at Utah State University. And in 2007 Clemson University announced the opening of its Department of Engineering and Science Education. These engineering education departments mark the emergence of the first academic departments devoted to the scholarship of engineering education. Between October and December 2007, positions (some of them endowed) for individual faculty to be hired with a focus on engineering education were announced by Arizona State, Michigan Tech, Ohio State, the University of Virginia, the University of Georgia, and Utah State.

As evidence of the continued growth of engineering education as a research discipline, the *Journal of Engineering Education* was repositioned in January 2003 to focus on publishing scholarly research in engineering education. This refined focus was celebrated in a special January 2005 issue entitled, "The Art and Science of Engineering Education Research,"[17] and will be marked again in an upcoming special 2008 issue tentatively titled "How People Learn Engineering." The journal has a five-year strategic plan (2005-10) in which it is pursuing seven initiatives to accelerate the growth of a community of scholars and practitioners dedicated to advancing engineering education through research[18].

More recent developments in engineering education research occurred in the form of the Engineering Education Research Colloquies (EERC) held in September and October 2005 and June 2006. The EERC were designed with the aim of laying the foundation for research-driven transformational change in engineering education. The EERC represented a collaborative effort of more than 70 engineering, science, and mathematics educators and researchers, learning scientists and practitioners. The result of the EERC was the identification of five research areas that can collectively serve as the foundation for the new discipline of engineering education: engineering epistemologies, engineering learning mechanisms, engineering learning systems, engineering diversity and inclusiveness, and engineering assessment methodologies[19].

There have been significant international developments as well. The Engineering Subject Centre of the UK Higher Education Academy has been offering subject-based support for teaching and learning in engineering since 2000 (initiated under the previous Learning and Teaching Support Network) and launched the journal *Engineering Education* in 2006. With the benefit of support provided by the government of the UK, the Centre has made tremendous progress in advancing engineering education research within British universities, and had a strong international influence. Under the leadership of the Carrick Institute for Learning and Teaching, a similar engineering subject center is under development in Australia, building upon a nascent infrastructure in place at many Australian universities. Singapore has lain out an aggressive national strategy for both science and engineering research and the translation of that research into improved practice in pre-college and collegiate education. The CDIO Institute for Africa, a transnational initiative for the continent of Africa, places heavy emphasis on educational theory.

CDIO (an acronym for Conceive-Design-Implement-Operate) is an international initiative that began at the Massachusetts Institute of Technology and now operates at universities in the several African countries, Australia, Canada, China, Denmark, Finland, Germany, Ireland, Italy, Sweden, the United Kingdom, and the US. There are indications that the Universiti Teknologi Malaysia will soon offer a doctoral degree in engineering education. Campus based centers of engineering education research also exist in the Middle East and South America. In short, engineering education research is a globally emergent phenomenon. In June 2007, the NSF supported a two-day International Conference on Research in Engineering Education (ICREE). Organized by the *Journal of Engineering Education*, the purpose of the conference was to accelerate development of engineering education as a discipline. Attendees were invited from among 225 engineering education researchers from around the world. At the conference, seventy-one domestic and international researchers and a ten-member program committee met to discuss current research in engineering education and associated disciplines, the implications of research for practical applications, and future directions[20]. The 2007 meeting is being followed by the international Research on Engineering Education Symposium (REES) which is being organized by an international planning committee and will be held in Davos, Switzerland July 7-10, 2008. In a related development, a special issue of the European Journal of Engineering Education is planned for Spring 2009.

Borrego[21] has summarized the applicability of Fensham's criteria for defining a academic field to engineering education research. She believes his structural criteria (academic recognition, presence of research journals, presence of professional associations, and regular research conferences) have been met. However, she sees mixed results with respect to his research criteria (with clear agreement that the criteria related to indicators of progress in the field, the presence of model publications and the presence of seminal publications have not been met and ambiguity, at best, on the others – the necessity of engineering knowledge in the conduct of the research, indication that researchers are asking distinctive questions not present in other fields, the strong presence of explanatory and predictive theoretical models, and the development or adaptation of research methodologies unique to the field). While she makes no comment on the progress of engineering education research in meeting Fensham's outcome criterion (i.e., that outcomes from the research have applicability to practice), we believe that there are positive indications of applicability of the engineering education research outcomes to the practice of engineering education. She observes that "engineering education now has the infrastructure, but not the research consensus to be called a distinct discipline." However, she also notes on-going calls for increased rigor as an appropriate next step in the field's development.

Necessary Actions to Support and Sustain the Field

Enumeration

We view engineering education research as well on its way to being an academic field and believe there are four essential elements to nurturing the continued emergence of engineering education research as a field:

1. Enhance capacity within the engineering community for the conduct, evaluation (as reviewers of conference and journal papers as well as grant proposals) and communication (as authors and public presenters) of high quality engineering education

research. This is done through mentorship, faculty development workshops, graduate student training, etc.

2. Develop, expand and sustain the community of scholars who will
    a. extend the boundaries of knowledge within the field,
    b. integrate knowledge with other fields and within subfields of engineering education research, and
    c. apply new knowledge to the solution of practical problems in engineering education both directly and by encouraging broad dissemination and use of the knowledge base
3. Develop mechanisms for identifying and pursuing research questions relevant to any and all elements of systems of engineering education.
4. Develop research tools and instruments that will aid in the development of a continually replenished body of knowledge

It is probably to be expected that these categories correspond to the People, Ideas, and Tools construct previously used by NSF in explaining its foci in the support of basic research[22]. Underlying each of the above is the funding to pursue the activities indicated. Such funding must be adequate, consistent, and available from both public and private sources. Private funds present a particular challenge. Except for isolated instances where a firm can see the direct business value of engineering education research (e.g., corporate learning and training development functions), engineering education research is likely to suffer at least the same challenges in obtaining corporate support as are seen in other engineering disciplines. Private foundation support is also a challenge because those foundations devoted to education research tend to see themselves as a) serving to support researchers in the cognitive and social sciences and not those in engineering education research; or b) supporting education research that crosses multiple broad disciplines of which engineering is only one; or c) focusing their support primarily at the pre-college level. Public support is likely to be limited to NSF as the largest funder of basic research. The mission agencies (e.g., Defense, NASA, and Energy) are likely to see engineering education research as too far removed from their mandates.

Status

Progress is being on all fronts. As indicated above, academic programs exist at a few institutions. Formalized doctoral research programs in engineering education research exist at Carnegie Mellon, Purdue, Tufts, Utah State, and Virginia Tech. For those not at this limited number of institutions, a series of NSF-supported workshops have served to alleviate pent-up demand among engineering faculty[23]. Engineering education research tools and instruments are being developed by many. A sampling of tools under development includes concept inventories[24], assessments of student engagement[25], research clearinghouses[26], and electronic communities of practice[27,28]]. The ICREE and REES meetings identified above hold particular promise for continually re-negotiating the range and span of research topics, theoretical and methodological frameworks, and particular research methods and tools used by the engineering education research community. Recognition and respect for the emerging field is exemplified in such activities at the ASEE 2006-2007 Year of Dialogue and the planned follow-on report[29].

However, there are two critical areas that threaten the maturation of engineering education research as a field: a) adequacy of funding and b) embracing the challenges and opportunities of use-directed basic research.

NSF has provided support in the past, but it has not been adequate or consistent. Although engineering education research has occurred in some form since at least the 1970s, only in the past 20 years has it received significant funding support from NSF. In 1991, an award was made to Richard Felder of North Carolina State University for a longitudinal study of the effects of innovative teaching (DUE-9150407) and in 1993 prestigious NSF Faculty Early Career Development (CAREER) awards were made to engineers Cynthia Atman of the University of Washington (DRL-9358516) and Martin Ramirez of Johns Hopkins University (DRL-9358518) with joint funding provided by three different NSF units. Atman's research examined how first-year engineering students developed strategies for solving open-ended, ambiguous problems that closely resemble problems in the engineering workplace, while Ramirez used research from cognitive science and educational psychology to develop a framework for teaching engineering so students learned how to make appropriate judgments for their work. By 2001, NSF initiated funding for two multi-institutional engineering and technology education-focused Centers for Learning and Teaching[10], which were headquartered in the engineering colleges at the University of Washington and Utah State University. Finally, the Engineering Education Program (EEP) was revamped in 2006 to more tightly focus on support for engineering education research[30]. In addition to support by the Divisions of Engineering Education and Centers and the Division of Undergraduate Education Research, engineers have seen occasional success with proposals submitted to the grant programs of the Directorate for Social, Behavioral, and Economic Sciences. Although limited support is available elsewhere at NSF, the only source of funding dedicated to engineering education research is provided by the Engineering Education Program. However, that source is limited to approximately $9 million which is also shared with the CAREER awards funded by NSF 's engineering directorate. A search of the NSF awards database (searching on program element 1340) shows fewer than 50 awards housed in the engineering directorate and devoted to engineering education research (80 other awards are housed in other divisions and were co-funded). As the number of engineering education researchers grows, the strain on this limited supply of funds will become increasingly significant.

The other major concern is how well the engineering education research community is able to negotiate both establishing itself as a free-standing discipline meeting all of Fensham's criteria [21] while also maintaining its utility to the larger goal of improving engineering education. This is the tension of being both a field of research which explores interesting questions when they arise and simultaneously being a field in service to the practical needs of engineering education. What makes the tension particularly severe is the magnitude of improvement desired in engineering education. The pressure is on for immediate solutions, and yet the culture and mores of higher education do not provide strong incentives for faculty to devote their time to adaption and use of knowledge versus the generation of new knowledge. This is part of what makes adaptation of proven innovations so difficult.

The Role of Leadership in Making a Policy Case

Thus far this paper has defined what engineering education research is and what actions are necessary to support and sustain it. However taking the required actions in an environment of multiple competing demands for time, attention, and resources will require leadership. This leadership must be exercised by the stakeholders of engineering education:

- Engineering education researchers,
- Directors of campus-based, national, and international centers devoted to engineering education research,
- Engineering faculty in general,
- Engineering department chairs and engineering college deans,
- Elected and staff leaders of professional societies (e.g., ASEE, the various disciplinary engineering societies, and the National Academy of Engineering), and
- Representatives of the large and small firms that employ engineers.

Leadership requires the identification of an aspirational vision as well as identification of specific goals and milestones to be achieved in pursuit of the vision. Most critically, leaders must inspire others a) to buy into the vision, b) to see how attaining the common vision will yield individual benefits, and c) to devote the effort required to achieve the vision. We can not wait for such leadership to naturally emerge. Our critical need is to actively cultivate in others, and exhibit ourselves, leadership that can take on five key tasks:

1. Guiding engineering education researchers in recognizing their potentially transformative value in restructuring engineering education to meet the needs of the 21st Century,
2. Helping individual engineering campuses to select the administrative structures (e.g., interdisciplinary centers, multidisciplinary graduate programs, or departments of engineering education), within which to situate engineering education research that are best suited to their local circumstances and cultures,
3. Structuring engineering education research as a full fledged discipline as indicated in above in the section on “Necessary Actions . . .” (many of the required actions are natural activities within recognized disciplines),
4. Applying the results of engineering education research to achieve improved learning in university and pre-college classrooms and industrial worksites—learning that positions engineers to recognize the full dimensions of the grand challenges facing the planet, to recognize the expertise required to address the challenges, and to assemble that expertise into functioning teams able to realize and deliver solutions satisfactory (with respect to technical, social, environmental, and global constraints) to their client populations.
5. Communicating the long-term social benefits that will result from investing intellectual, human, and financial resources in engineering education research. Such communication must be crisp, coherent, unified across engineering disciplines, and delivered by recognized authorities.

Communicating the Public Policy Case

The policy case must be made not only to the academic and professional society sectors, but also to leaders in the political, media and think tank, economic, business, and independent non-profit sectors. While a single core case will be necessary for coherence, it is likely that highlighting the benefits to be achieved may require some degree of tailoring to the specific interests of each audience.

Non-Technical Audiences

Making the case to the political, business, media and think tank audiences will be relatively straightforward. It is principally a matter of giving clear indication of the benefits to be accrued as well as periodic updates of progress being made. Given the current concerns about the global competiveness of the US economy, the recognized need for engineering education to prepare more adaptable and agile graduates for a rapidly evolving world, and the technological dimensions of national and global grand challenges, this case is already being made in a variety of fora[31, 32, 33]. There are additional opportunities to be exploited by developing partnerships with national media to develop pop-culture appeal in television programming (e.g., technologically-focused prime time shows such as *N3UMBERS* and *CSI*), music, and/or games. This can be partly accomplished by partnering with national professional organizations, major networks, television producers, educators, media consultants, etc., to develop concept, strategy, and content ideas."

Special considerations come into play in communicating to potential public and private funders, particularly those who control the purse strings within state and federal agencies as well as their legislative and Congressional overseers. Though many legislators are concerned about their state's or the nation's competitiveness, most are not aware of engineering education research, nor have they considered it as a policy option. Despite this lack of political momentum, a general interest in STEM education issues and a search for solutions among policymakers may be a sufficient opening to raise the profile of engineering education research. It is vital that academics with an interest in engineering education research take action. Specific guidance on engaging members of the Congress has previously been provided[34] and much of it applies to state legislatures as well. Engineering education researchers, as with their most successful peers in other sectors, must overcome their disdain for the political process and quickly learn to engage and communicate with potential funders. The competition is much too stiff to sit back and hope that logic and good will alone will suffice.

Technical Audiences

The more challenging case presentation will be to the academic and professional society sectors, this case will need to be made on the basis of the long-term benefits to be achieved by the overall engineering enterprise, comparable to the case for internal corporate research and development. However, unlike corporate R&D, making this case will involve a significant challenge to the culture of the overall enterprise. It requires broadening the accepted definition of what engineering is to encompass the engineering of the profession itself. This case must be made to peer faculty, engineering administrators, institutional leaders, as well as the leadership and rank-and-file of professional societies.

Because it is linked to issues of status, culture, and identity in both higher education and in engineering disciplines, making the policy case for the value of engineering education research as use-directed basic research requires a subtle and delicate approach. Most will accept the potential of engineering education research to address very thorny challenges (e.g., preparation of an engineering workforce to meet the multifaceted challenges of the new century)[31]. Where there is controversy is whether such work should be considered a new area of engineering research. Engineering education researchers must boldly meet this challenge. We must transform our community's culture from that of habitués of a hidden society of eager amateurs to a confident scholarly community secure in the value of our work and actively engaged in providing pivotal leadership in an exciting research area whose knowledge products will enhance the quality of millions of lives. After so many years on the fringes, this will not be an easy transition, but the health of our field depends upon it. Part of making this transition will require holding ourselves and our peers to ever increasing standards of excellence. We must stand as co-equal peers with members of other research fields without a need for excuses or explanations. But we must also dare to lead. Changes in the engineering operating environment are well documented[32]. The tasks engineers are called upon to perform have changed. The populations from which we must draw future generations of engineers have changed. The types of knowledge engineers are expected to posses have changed. In the face of these realities, engineering education researchers hold the keys to helping the profession successfully make the transition to the next major evolution in engineering.

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