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Engineering Education: Departments, Degrees and Directions*

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The idea that effective reform in engineering and science education should be guided through systematic research and outcomes assessment should be self-evident; however, historically, the educational practices and beliefs held by faculty in higher education have been largely anecdotal and based on personal experience. There is growing acceptance of discipline-based education as a valuable research enterprise, on the same level as research into, say, mechanical engineering or organic chemistry. Evidence of innovative ways that discipline-based education programs are taking root in higher education include the establishment of cross-disciplinary departments in science, technology, and engineering education. These departments bring together faculty whose research area is education, who can tackle large-scale problems across the curriculum in addition to discipline-specific research projects. These departments seek to ensure that: 1) faculty engaged in engineering and science education research conduct rigorous, scholarly work, 2) education research is accessible and valued by faculty in 'traditional' engineering and science disciplines, and 3) the next generation of engineering and science educators will promote and apply education research. In this paper, we will review the details behind the formation of departments that include engineering education, specifically highlighting their roots, structures and purpose. We will also provide information on typical courses, programs and degrees offered by these departments, and career paths for their graduates. Finally, we offer examples of how the discipline of engineering education has been fostered at institutions without a dedicated department, such as centers and other 'hybrid' models.

Keywords: discipline-based education research; engineering education curriculum; graduate education

1. INTRODUCTION

THE CALL for a transformation in how engineers are educated is well documented [1–5]. The major reasons for this call for change are the small proportion of students seeking careers in engineering (compared to other countries), the need for a diverse engineering workforce, and the effects of rapid technological change and globalization. Future engineers will need critical thinking and problem-solving skills beyond those of previous generations in their disciplines, and in fact must have the creativity and communication skills to innovate across disciplines. Engineering practice is being shaped by a wide range of divergent global factors, and it is incumbent upon institutions of higher education to transform engineering education in a sound and insightful way to prepare students for the challenges ahead [6]. Through the growth and development of engineering education as a discipline, research initiatives and a broad range of cross-disciplinary collaborations are producing a new culture in which discipline-based education research is applied, and inclusive, evidence-based curricula are implemented. An ever-increasing cadre of engineering educators is conducting systematic research [7–9], and as a result, colleges of engineering are beginning to implement reward systems for legitimate, profitable engineering education research through the tenure process, in addition to initiating engineering education programs.

A natural outgrowth of rigorous research in engineering education is the development of degree programs that ensure continuation and growth of the discipline. The graduates of these programs should be prepared to:

1. Conduct and direct cutting-edge education research, including the areas of epistemologies, learning mechanisms and systems, pedagogical implementation, diversity and inclusiveness, and assessment.
2. Apply the results of such research to the development, teaching, and assessment of

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courses, curricula, and educational policies in academic and non-academic settings.
3. Be prepared for academic, government, and industry positions related to the lifelong education of engineers and scientists.
4. Actively participate and act as leaders in their fields through professional organizations, conferences, government organizations, workshops, and related activities to advance engineering and science education, and to develop highly qualified engineers, scientists, and discipline-based education researchers.

Graduates from engineering and science education programs are in high demand in academia, industry, and government. Job functions include research, teaching, higher education administration, outreach, and public service in research and educational policy. An increasing number of universities are beginning to realize that the presence of discipline-based education researchers can have a real and positive impact on the education activities of a department [10]. For example, currently in chemistry there are more positions for chemical education researchers than there are qualified people to fill these positions [10]. And there is no shortage of students interested in pursuing engineering and science education research for the purpose of acquiring academic positions. A survey of prospective students to one engineering education program indicated that nearly 79% were interested in employment at the college level [11]. There is also evidence that these programs are in high demand, with a steady stream of applicants for available positions. However, only four departments that include engineering education exist in the US to date, in spite of the fact that the demand for engineers outnumbers the demand for physical scientists [12].

2. DEPARTMENTS OF ENGINEERING EDUCATION

At the time of this writing, there are four academic units in existence within colleges of engineering and/or science that include engineering education: the School of Engineering Education at Purdue University, the Department of Engineering Education at Virginia Tech, the Department of Engineering and Technology Education at Utah State University, and the Department of Engineering and Science Education at Clemson University. Although all four units originated from existing academic programs serving undergraduates (mainly first year engineering students), these represent four different models that capitalize on institutional strengths to promote the discipline of engineering education. Details on the origins and current profiles of these departments are summarized in Table 1.

The faculties of these departments are highly interdisciplinary, having degrees from engineering, sciences, education, psychology, language arts, mathematics, and others. The daily interactions of these diverse groups lead to highly creative proposals and scholarship. The key element of these departments is that they have a critical mass of educational researchers that work together, bringing different knowledge bases, perspectives, research methods, and writing styles to the group. The resulting synergy is very powerful.

Research areas within these departments span all levels of pre-college and college education, graduate student development, faculty development, and the full range of engineering education research areas as defined by the Engineering Education Research Colloquies [13] and the Center for the Advancement of Scholarship in Engineering Education (CASEE) Research

Table 1. Profiles of four academic units in engineering education currently in existence at Purdue University, Virginia Tech, Utah State University, and Clemson University. (FT = full time)

Institution	Academic Unit	Important Dates	Faculty Profiles	Graduate Programs and Degrees
Purdue University	School of Engineering Education	Established: 2004 PhD program: 2005	19 FT, 9 courtesy appointments; Academic backgrounds in engineering, psychology, and education	Ph.D. in Engineering Education; M.S. in Engineering Education
Virginia Tech	Department of Engineering Education	Established: 2004 PhD program: 2008	14 FT Academic backgrounds in engineering, English, communications, linguistics, math and learning sciences	Ph.D. in Engineering Education Certificate in Engineering Education
Utah State University	Department of Engineering and Technology Education	Established: 2003 PhD program in Engineering Education: 2008	7 FT Academic backgrounds in engineering, technology education	Ph.D. in Engineering Education; M.S. in Engineering and Technology Education
Clemson University	Department of Engineering and Science Education	Established: 2006 PhD program: 2011	7 FT Academic backgrounds in engineering, chemistry, mathematics, physics and science education	Certificate in Engineering Education

Thrusts [14, 15]. Research reflecting what constitutes rigorous research in engineering education [16], and the difficulties encountered by engineering faculty as they learn engineering education research methods [17] has documented the history and development of engineering education as a discipline.

While the establishment of engineering education departments is a relatively recent phenomenon, the sciences have taken a different path in the establishment of education graduate programs in the discipline. Both physics and chemistry have a well-established history of education research programs within the disciplinary department. Over the past twenty years the number of such programs has grown dramatically. For example, there are over thirty education-focused programs in chemistry departments in the US [18], and over forty in physics departments [19, 20]. While not all of these grant degrees, there is a fairly long and robust history of discipline-based education research in the sciences. This model has both advantages and drawbacks over the model that is emerging for engineering education. The inclusion of education research within a disciplinary department provides legitimacy and immediacy for the program, while housing it in a separate department moves education away from the disciplines, and could make it easier for the rest of the disciplines to ignore the findings from those departments. On the other hand, discipline-based education researchers often form a minority of one (of the 30+ programs in chemistry, only seven have more than one faculty), and the tenure and promotion requirements for faculty in a disciplinary department may be problematic. Having a separate department allows separate tenure and promotion guidelines, and brings more faculty together on a day-to-day basis to provide a critical mass. This allows for cross-fertilization of ideas and support of faculty in what is still, for some, a controversial area.

3. COURSES, CERTIFICATES AND DEGREES

All four academic units offer courses in engineering education; for three of these, courses can lead to a Ph.D. (Purdue, Virginia Tech and Utah State), and for three, a certificate can be earned (Purdue, Virginia Tech and Clemson). Courses at all four institutions include pedagogy, research methods, a practicum and a seminar. While these departments have similar visions that seek to prepare future faculty and build outcomes-based programs, each has a unique interpretation of that vision through its features, courses, and collaborations. These are summarized in Table 2, roughly in the order in which the departments were established. One similarity between all departments is the requirement that its graduate students specialize in a 'traditional' engineering discipline, in addition to their own area of education research. Some approach this by requiring a bachelors and/or masters degree in an engineering discipline (Clemson, Utah State and Purdue), and others have embedded the specialization within the graduate course requirements (Virginia Tech). Such disciplinary concentrations are required to ensure that graduates will meet the regional accreditation requirements of a minimum number of graduate credits required to teach in a traditional engineering discipline.

The School of Engineering Education at Purdue University [21] graduated ten PhDs as of August 2009. One is employed in a science museum; the others are employed in academic units in several capacities. These include a post doctoral researcher, a research fellow, assistant professors (six total; two in engineering education, one in mathematics education, two in civil and mechanical engineering, and one in electrical and computer engineering and computer science), and an administrator. The Purdue ENE PhD Program has ten competency areas and portfolio-guided assessment. The coursework requirements are organized into three categories: Engineering Education Foundations, Secondary Engineering Expertise, and Research Preparation.

At Virginia Tech [22], 14 graduate certificates (requiring 13 semester hours, including a practicum) have been awarded, and approximately 10 additional students are working on the certificate at the time of this writing. Most of the certificate recipients are still in graduate school, although others are in faculty positions and in engineering positions in industry. The certificate in Engineering Education is complementary to a Future Professoriate certificate offered by the Graduate School. The Engineering Education program has eight graduate courses that form the core of the program and are offered on a rotating basis. Completion of a Ph.D. in engineering education requires course work in Education and in a 'traditional' engineering discipline. The purpose of the latter concentration is so that the graduates of the program meet regional accreditation requirements to teach at the graduate level in traditional engineering departments. The program currently has 14 Ph.D. students, with an increase of about five students per year. The plan is to reach a steady state of 25 students with 5–6 degrees awarded per year.

The Doctorate of Philosophy in Engineering Education at Utah State University is offered through the Engineering and Technology Education Department [23], and the first cohort of students started the program in Fall 2009. Emphasis is on the learning and teaching of engineering design, producing students with proficiency in developing engineering design skills in others, and expertise in research into how those skills are best learned and taught. The optimum number of graduate students in this program will be 15 to 20 full-time students. In addition, the department also offers a PhD in Education through the College of Education, with students specializing

Table 2. Courses and core areas of study for each of the four engineering education departments.

Program	Core Areas	Courses
Purdue University	Engineering Education Foundations	Introduction to Engineering Education (1 cr) History and Philosophy of Engineering Education (3 cr) Theories of Development and Engineering Thinking (3 cr) Leadership, Policy and Change in STEM Education (3 cr) Content, Assessment, and Pedagogy (3 cr) Seminar in Engineering Education
	Secondary Engineering	Courses in an engineering field other than engineering education (9 credit hours minimum)
	Research Preparation	Engineering Education Inquiry (3 cr) Research Methods Elective, in Coll. of Ed. or elsewhere (3 cr) Social science statistical methods (3 cr)
Virginia Tech	Engineering Education Core	Foundations of Engineering Education (3 cr) Seminar (offered jointly with Clemson) taken every semester (1 cr) Assessment Techniques in Engineering Education (3 cr) Design in Engineering Education and Practice (3 cr)
	Engineering Concentration	Courses in an engineering field other than engineering education (15 cr min)
	Engineering Communication	Communication in Engineering Curricula: Theory, Practice, and Pedagogy (3 cr) Evaluating Engineering Communication Assignments (1 cr)
	Research Preparation	Statistical methods (6 cr) Engineering Education Research Methods (3 cr) Advanced Engineering Research Methods (3 cr)
	Engineering Instruction	Practicum in the Engineering Classroom (3 cr min)
	Education Concentration	Concentration in the School of Education (9 cr min)
Utah State University	Engineering Education Core	Evaluation and Assessment (3 cr) Cognition (3 cr) Educational Foundations (3 cr) Teaching and Learning Foundations (3 cr) Research Methods (3 cr) Seminar (3 cr) Finance & Grant Writing (3 cr)
	Area of Specialization	Courses in an engineering field; at least 3 credits outside of engineering education (9 cr min)
	Research Component	Research Theory (3 courses – 9 cr) Dissertation (24 cr min.)
Clemson University	Pedagogy and Instruction	Teaching Undergraduate Engineering (3 cr) Teaching Undergraduate Science (3 cr) Theories of Instruction (3 cr)
	Research	Engineering and Science Education Research Methods (3 cr) Elective in School of Education, or Departments of Psychology, Sociology, or Experimental Statistics (3 cr)
	Professional Preparation	Current Topics in Engineering and Science Education (3 cr) Preparing for the Professoriate (3 cr)

in Curriculum and Instruction. Students completing this specialization program receive a degree with an area of emphasis in engineering and technology education. Graduates from this program enter teaching and research positions in technology teacher education, engineering technology programs and become industrial trainers.

Clemson's Department of Engineering and Science Education [24] is building on experience with a Chemistry Education degree program, now in its tenth year. While an Engineering and Science Education degree program is not yet in place, twelve graduate students are actively conducting education research while pursuing doctoral degrees in engineering disciplines (mechanical, bioengineering, civil, industrial, and electrical) as well as science disciplines (mathematics and chemistry). Six students have completed a Certificate in Engineering and Science Education, with another 19 students currently pursuing the certificate. The certificate requires a total of 11 credits earned mainly through the department, with some courses offered through the School of Education and other social sciences. Most of these students are seeking academic careers that involve teaching and research at a college or university.

4. CAREER OPPORTUNITIES FOR GRADUATES

When discussions about implementation of graduate programs in discipline-based education research (science or engineering) are initiated, one of the most common concerns is whether graduates of such programs are employable. Certainly no program wants to produce graduates who are not qualified or in demand. Institutions considering development of a department or a graduate degree program in engineering education might find it instructive to look at the history of such endeavors in the sciences, which have been in existence somewhat longer. As indicated previously, there is an extensive and growing presence of discipline-based education researchers in both physics and chemistry departments across the country. While engineering and the sciences are often separated, and there are some differences, in fact much of the research base in engineering education and science education (at the college level) is quite complementary, and it makes sense for each discipline to communicate, collaborate, and prevent 'wheel reinvention'.

For example, in recent years the number of faculty positions advertised that specifically target chemistry education researchers has outstripped the number of qualified applicants (i.e. those graduating with a Ph.D. with a research emphasis in chemistry education). The number of departments that recognize the merit of faculty members with expertise in curriculum development, assessment, and evaluation is growing—and with it the demand for graduates. A similar situation exists in physics, and one might imagine that engineering would follow suit. Specifically, at Clemson University, over the past five years, four Ph.D. researchers in chemistry education (two with degrees in chemistry, and two with degrees in curriculum and instruction) have been graduated. Three of those students have taken faculty positions (two in chemistry departments and one in education) and one is in a postdoctoral research associate position. Even though this is a small sample from one research group, it seems clear that the new department at Clemson has the potential to generate a number of qualified researchers in science and engineering, either as graduates of disciplinary departments or, when the new Ph.D. program is approved, as graduates with a Ph.D. in Engineering and Science Education. This program will build on courses already in place that focus on pedagogy and instructional theories, education research methods, and preparation of future faculty.

5. OTHER MODELS FOR ENGINEERING EDUCATION RESEARCH AND SCHOLARSHIP

Other models for conducting engineering education research that are currently established at institutions around the country include campus-based centers and national centers. Goals for campus-based centers vary widely based on campus culture and need, with centers responding to the college/department support received, faculty support and involvement, and assessment mechanisms. For example, one of the first centers located in a college of engineering, the Center of Engineering Learning and Teaching (CELT) at the University of Washington, is funded through several sources that include an endowed chair that is held by the center director and support from the college and industry for instructional development. Instructional support delivered by Center personnel includes individual consultations, workshops and other endeavors to support faculty and departments within the college. CELT has a research focus on learning and teaching and receives additional funding from grants at the national level. They are also involved with graduate courses on learning and teaching. One of the more recent centers, the Engineering Education Innovation Center at Ohio State University, was initiated by an endowment from Honda. There is a rapidly growing list of centers focused on engineering and science education, which is currently available on the CASEE website [25].

The structures and people involved with these centers vary widely. Most include faculty who have their sole focus on engineering education, but also include faculty who are passionate about teaching and learning whose research focus is in other engineering disciplines. The types of graduate and undergraduate students who are involved in the center and the function of various staff members also vary based on center structures. Funding sources shape the structure and culture of these centers to a large extent. Most centers receive funding from both internal sources (such as funding for full-time staff from the college) and external sources (such as endowment funds, corporate donations, contracts and grants) [26].

The research areas of each center are driven by the interest of individuals involved. In addition, centers have the ability to respond to changing campus and national research agendas. This gives direction to the research and allows center personnel to engage in the national dialogue about engineering education [27].

Another model for engineering education includes national centers, such as CASEE within the National Academy of Engineering. The structure and nature of national centers also vary widely depending on the funding source and goals of the program. Many campus-based centers started as national centers that were funded by organizations such as the National Science Foundation and continued through the funding models explained above. Many have faculty from several institutions collaborating on common research themes.

6. CONCLUSIONS AND FUTURE DIRECTIONS

Discipline-based education research can provide the foundation and impetus for change in the way future engineers and scientists are educated. An overriding question is whether or not we have the will to base our educational practices on evidence-based research as we do in our traditional academic disciplines. There are a number of viable models for how this research base can be developed and disseminated. Whatever mode is employed, in order for systemic change in engineering education to occur it is imperative that the findings from this research be widely implemented. The increasing numbers of engineering education departments and the acceptance of faculty whose research area is discipline-based education research bode well for the needed changes. However, not all institutions have the resources (or will) to form new departments, or hire discipline-based education research faculty. It is our hope that academic units like those profiled here will form the nucleus of a community of scholars, whose goal is systemic change. The graduates of these departments will be meeting critical challenges such as bridging the gap between research and practice to improve the discipline as a whole [28]. It is anticipated that future efforts will include a 'Collaboratory Center' founded by these four departments that will serve as a focus for large-scale engineering education research projects and as support for individual researchers in disciplinary departments by building a repository of shared data, tools, and research findings.

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