Guest Editorial

Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering

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Engineering education research (EER) has been on the fast track since 2004 with an exponential rise in the number of Ph.D.s awarded and the establishment of new programs, even entire EER departments. The National Research Council's *Discipline-Based Education Research* (*DBER*) report (National Research Council, 2012) captures the state-of-the-art advances in our understanding of engineering and science student learning and highlights commonalities with other science-based education research programs. The *DBER* report is the consensus analysis of experts in undergraduate education research in physics, chemistry, biology, geosciences, astronomy, and engineering. The study committee, chaired by Susan Singer, also included higher education researchers, learning scientists, and cognitive psychologists. A central aspect of the *DBER* report is the focus on and application of research in the education, learning, and social-behavioral sciences to science and engineering curricula design and teaching methods.

Froyd, Wankat, and Smith (2012) identified five major shifts in engineering education in the past 100 years:

1. A shift from hands-on and practical emphasis to engineering science and analytical emphasis
2. A shift to outcomes-based education and accreditation
3. A shift to emphasizing engineering design
4. A shift to applying education, learning, and social-behavioral sciences research
5. A shift to integrating information, computational, and communications technology in education

They also argue that the first two shifts are completed and the last three are in progress.

The *DBER* study is particularly focused on Shift 4, applying education, learning, and social-behavioral sciences research. The *DBER* report supplements and complements a flurry of activities in engineering education research, such as the emergence of Ph.D.-granting departments in colleges of engineering (Purdue, Virginia Tech, and many others in the United States and abroad; Benson et al., 2010) as well as the establishment of centers for engineering education research (University of Washington, Michigan State University, University of Pittsburgh, and many others; see Engineering Education Research and Teaching Centers, 2013, for a detailed list), and in faculty professional development

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projects, such as the Rigorous Research in Engineering Education (RREE) project (Smith, 2006; Streveler, Borrego, & Smith, 2007; Streveler & Smith, 2006, 2010).

The emergence of DBER Ph.D. programs in science and engineering disciplines will substantially enhance the frequency and quality of research and will provide the knowledge and evidence-based foundation to advance the state-of-the-art of science and engineering education.

Discipline-based education research comprises related research fields that investigate learning and instruction within a discipline that are grounded in the priorities, worldview, knowledge, and practices of that discipline. Research by DBER scholars has generated insights with the potential to improve undergraduate education in science and engineering. For example, many research studies and syntheses report that evidence-based approaches to teaching that actively engage students in their own learning are more effective than traditional lecturing. Yet evidence that these educational approaches (and others) are effective has not yet prompted widespread changes in teaching practice. There is no magic solution for moving from the evidence to implementing effective teaching practices.

The key findings from the consensus study are

> Discipline-based education research is a small but growing field of inquiry. At this time most efforts to develop and advance DBER as a whole are taking place at the individual field of DBER.
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> Among the disciplines studied, DBER is in different stages of development. The scholars and the individual fields represented have made notable inroads in terms of establishing their fields but still face challenges in doing so.
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> Discipline-based education research is inherently interdisciplinary, and the blending of a scientific or engineering discipline with education research poses unique professional challenges for DBER researchers.
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> There are many pathways to becoming a discipline-based education researcher. At the time of this study, many established DBER scholars were trained in traditional disciplinary graduate programs and migrated into DBER. These border crossers are particularly common in biology, geosciences, and astronomy education research.
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> Conducting DBER and using DBER findings are distinct but interdependent pursuits.
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> Education research centers enable faculty to use DBER findings, introduce students to DBER as a career option, and support collaborations among faculty. Few of these centers currently exist, and even fewer have a singular focus on DBER. (p. 42)

In the following, we provide highlights from the report on what is known about undergraduate learning in engineering and science, the challenges to broad implementation, and recommendations for improving higher education.

Students have incorrect understandings about fundamental concepts – particularly phenomena that are not directly observable, such as those involving very large or very small scales of time and space. Across the disciplines, concept inventories are being used to identify student misconceptions that hinder their learning. Our understanding of how to help students change these conceptions is in the early stages, but DBER has identified some effective instructional techniques including "bridging analogies." This approach links students' correct understandings and the situation about which they harbor a misconception. For example, a student may not believe that a table can exert a force on a book resting on its surface but accepts that a spring under the same book is exerting a force on the book. Linking these two ideas, with perhaps an intermediate of a book resting on a foam block, can move the student toward a correct understanding of forces.

Students are challenged by important aspects of the domain that can seem easy or obvious to experts. For instance, when solving problems, students tend to focus on the superficial aspects of a problem rather than its deep structure. Instructors may have an "expert blind spot" and not recognize how different the student's approach is from their own; this blind spot can impede effective instruction. Several strategies appear to improve problem-solving skills, such as providing support and prompts – known as "scaffolding" – as students work their way through problems. Having students work in groups and incorporating open-ended, authentic problems and activities into assignments also enhance problem-solving abilities.

Students in all disciplines also have trouble understanding representations like graphs, models, and simulations. Understanding and using representations are essential in each science and engineering domain, and research has clearly identified learner difficulties in translating between representations, e.g., realistic (picture or text), diagrammatic (free-body diagram), and symbolic (mathematical). Using multiple representations in instruction is one way to move students towards expertise. The January 2013 special issue of this *Journal* focused on representations in engineering practice.

Research is emerging on improving student ability to transfer learning, enhancing their own thinking about their learning (metacognition), and better understanding the role of the affective domain in undergraduate science and learning. The report recommends that future DBER investigations include research that explores similarities and differences in learning among various student populations, longitudinal studies that can shed additional light on how students acquire and retain understanding (or misunderstanding) of concepts, and studies that investigate student outcomes other than test scores.

Continuing to deepen the DBER research base is essential for transforming undergraduate education, and this need calls attention to the professional development of DBER scholars. Discipline-based education research requires deep disciplinary expertise and an understanding of learning and teaching. Although they have made progress in establishing their fields, DBER scholars still face challenges in identifying pathways for training and professional recognition. Institutions and professional societies can help by supporting venues for these scholars to share their research findings at meetings and in high-quality journals.

Strategies are also needed to translate the findings of DBER and related research into practice. It is one of several fields, including higher education research and the work of professional development experts in learning and teaching centers, that investigate approaches to changing faculty teaching practice. A number of barriers must be overcome, including the faculty reward system, the relative valuing of teaching and research, needed support for faculty in learning to use research-based practices, worry about student evaluations, and workload concerns.

Efforts to change teaching practice are more likely to succeed if they use methods and techniques supported by research on motivating adult learners, an approach that has been shown to be successful in engineering education. Change strategies should also include a deliberate focus on faculty conceptions about teaching and learning. The evidence also points to the importance of recognizing the cultural and organizational norms of the department and institution and then working to address those norms that pose barriers to change in teaching practice. Studies of organizational and behavior change that could aid the translation of DBER findings into practice are needed.

The *DBER* report recommends that institutions, disciplinary societies, and professional societies support faculty efforts to use evidence-based teaching strategies in their classrooms. In addition, they should work together to prepare future faculty who understand research findings on learning and teaching and who value effective teaching as part of their career aspirations. Implementing these recommendations is the first step in translating the research findings into practice.

A follow-up project, the DBER Practitioner Guide, was launched in January 2013. The guide, which features a case-study approach, will focus on translating the evidence-based practices identified in the *DBER* report into implementable approaches for faculty in science and engineering disciplines. The anticipated publication date is spring 2014.

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