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

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Executive Summary

The United States faces a great imperative to improve undergraduate science and engineering education. Preparing a diverse technical workforce and science-literate citizenry will require significant changes to undergraduate science and engineering education. These changes include supporting an emerging, interdisciplinary research enterprise that combines the expertise of scientists and engineers with methods and theories that explain learning. This enterprise, discipline-based education research (DBER), investigates learning and teaching in a discipline from a perspective that reflects the discipline's priorities, worldview, knowledge, and practices. Informed by and complementary to research on learning and cognition, DBER already has generated insights that can be used to better prepare students to understand and address current and future societal challenges.

Recognizing DBER's emergence as a vital area of scholarship and its potential to improve undergraduate science and engineering education, the National Science Foundation requested that the National Research Council convene the Committee on the Status, Contributions, and Future Directions of Discipline-Based Education Research to conduct a synthesis study of DBER. Looking across physics, chemistry, engineering, biology, the geosciences, and astronomy, the committee's charge was to

- synthesize empirical research on undergraduate teaching and learning in the sciences,
- examine the extent to which this research currently influences undergraduate science instruction, and

- describe the intellectual and material resources that are required to further develop DBER.

DEFINING DBER

The committee defined DBER as a collection of related research fields. DBER scholars in physics, chemistry, engineering, biology, the geosciences, and astronomy study similar problems, use similar methods, and draw on similar theories. However, the DBER fields also exhibit important differences that reflect differences in their parent disciplines and their histories of development.

As defined by the committee, the goals of DBER are to

- understand how people learn the concepts, practices, and ways of thinking of science and engineering;
- understand the nature and development of expertise in a discipline;
- help identify and measure appropriate learning objectives and instructional approaches that advance students toward those objectives;
- contribute to the knowledge base in a way that can guide the translation of DBER findings to classroom practice; and
- identify approaches to make science and engineering education broad and inclusive.

To address these goals, DBER scholars conduct a wide range of studies that includes basic and applied research. Both types of research are valuable and important.

High-quality DBER combines expert knowledge of a science or engineering discipline, of the challenges of learning and teaching in that discipline, and of the science of learning and teaching generally. This expertise can, but need not, reside in a single DBER scholar; it also can be strategically distributed across multidisciplinary, collaborative teams.

SYNTHESIS OF THE LITERATURE

DBER scholars have devoted considerable attention to effective instructional strategies and to students' conceptual understanding, problem solving, and use of representations. Key findings from DBER are consistent with cognitive science research and studies in K-12 education.

To gain expertise in science and engineering, students must learn the knowledge, techniques, and standards of each field. However, across the disciplines, the committee found that students have incorrect understandings about fundamental concepts, particularly those that involve very large

or very small temporal and spatial scales. Moreover, as novices in a domain, students are challenged by important aspects of the domain that can seem easy or obvious to experts, such as problem solving and understanding domain-specific representations like graphs, models, and simulations. These challenges pose serious impediments to learning.

DBER clearly shows that research-based instructional strategies are more effective than traditional lecture in improving conceptual knowledge and attitudes about learning. Effective instruction involves a range of approaches, including making lectures more interactive, having students work in groups, and incorporating authentic problems and activities.

To enhance DBER's contributions to the understanding of undergraduate science and engineering education, the committee recommended the following:

- Research that explores similarities and differences among different student populations
- Longitudinal studies—including studies of the K-12/undergraduate transition—to better understand the acquisition of important concepts and factors influencing retention
- More studies that measure outcomes other than test scores and course performance, and better instruments to measure these outcomes
- Interdisciplinary studies of cross-cutting concepts and cognitive processes

INCREASING THE USE OF DBER FINDINGS

The committee concluded that DBER and related research have not yet prompted widespread changes in teaching practice among science and engineering faculty. Different strategies are needed to more effectively translate findings from DBER into practice. These efforts are more likely to succeed if they are consistent with research on motivating adult learners, include a deliberate focus on changing faculty conceptions about teaching and learning, recognize the cultural and organizational norms of the department and institution, and work to address those norms that pose barriers to change in teaching practice.

To increase the use of DBER findings, the committee recommended that current faculty adopt evidence-based teaching practices to improve learning outcomes for undergraduate science and engineering students, with support from institutions, disciplinary departments, and professional societies. Moreover, institutions, disciplinary departments, and professional societies should work together to prepare future faculty who understand the findings of research on learning and evidence-based teaching strategies.

ADVANCING DBER AS A FIELD OF INQUIRY

Advancing DBER requires a robust infrastructure for research that includes adequate, sustained funding for research and training; venues for peer-reviewed publication; recognition and support within professional societies; and professional conferences. To these ends, the committee recommended that science and engineering departments, professional societies, journal editors, funding agencies, and institutional leaders clarify expectations for DBER faculty positions, emphasize high-quality DBER, provide mentoring for new DBER scholars, and support venues for DBER scholars to share their research findings at meetings and in high-quality journals. For their part, DBER scholars can increase their interactions and continue drawing on related disciplines (e.g., cognitive science, educational and social psychology, organizational change, psychometrics). Finally, Ph.D. programs and postdoctoral opportunities in the individual fields of DBER can advance DBER by educating scholars who will contribute to the educational research agenda and translate that research to others.