Guest Editorial

Promoting DBER–Cognitive Psychology Collaborations in STEM Education

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Most engineering education researchers can share stories about working in an emerging and "in-between" discipline. From questions of rigor to confusion over how engineering education research differs from teaching to making the case that our work qualifies as research, our community identity has been partially formed from these tensions. Such experiences have led to engineering and other STEM disciplines coining the phrase "discipline-based educational research," or DBER, to try to clarify our role and identity. In the July 2017 issue of *JEE*, Henderson and colleagues published an editorial promoting the formation of a STEM DBER alliance, outlining its benefits to the science and engineering education communities (Henderson et al., 2017). We wholeheartedly agree with all the points made in that editorial and here propose engineering education would be served by an even "larger tent" that includes collaborations between the DBER and Cognitive Psychology (CogPsy) communities. Below, we explore steps in this direction and possible ways forward.

Contrasting Goals, Research Traditions, and Language of DBER and CogPsy

In September 2016, an NSF-funded conference brought together 34 researchers from the DBER and CogPsy communities to enhance collaborations and to identify ways to bring the two communities together around research questions of common interest (McDaniel et al., 2017). Recommendations to promote collaborations were broadly grouped around four themes: (a) establishing the legitimacy of collaborative DBER/CogPsy research, (b) promoting collaborations between DBER and CogPsy researchers, (c) enhancing communication between the two communities, and (d) uniting DBER researchers across disciplines (which was addressed thoroughly in Henderson et al., 2017). While there was keen interest in forging future collaborations, it became clear that often the goals, research traditions, and language of the two communities differ, creating barriers to collaboration.

Goals

The goals of DBER researchers often focus on influencing classroom practices that, in turn, affect student learning. Qualitative data or evidence drawn from small samples can be sufficient to motivate colleagues to make changes to their instruction, which can then be iterated and refined in situ based on the assessment of student learning. On the other hand, CogPsy research most often focuses on revealing the processes and underpinnings of effective practices such that causal connections between interventions and learning outcomes can be investigated.

Journal of Engineering Education
January 2018, Vol. 107, No. 1, pp. 5–10
DOI 10.1002/jee.20188

Research Traditions

In the DBER research tradition, studies aim for ecological validity and, as a result, are most commonly conducted in classrooms, necessitating quasi-experimental, nonexperimental, and correlational techniques. In contrast, CogPsy research takes place in laboratory settings that enable more controlled experimental techniques such as within-subjects designs to examine the influence of retrieval practice on learning. But these promising findings are not often applied or studied in teaching at-scale.

Additionally, in DBER studies it is difficult or impossible to control for influences that characterize CogPsy research. One example is a DBER researcher interested in testing the effects of retrieval practice in the classroom by implementing quizzing. If found to be effective, it may matter little why the benefit was obtained (e.g., direct effects of retrieval, increased metacognitive accuracy, better student study habits) since the desired goal is improved student learning. In contrast, a CogPsy researcher would proceed with more controlled, experimental investigations to identify the causes of this effect to make its subsequent application more precise. The level of control possible in a laboratory setting would likely have negative effects were it to be attempted in a classroom.

Language and Terminology

Language also forms a barrier to collaboration since constructs can be broadly and vaguely defined both across and within these two communities. One example is the commonly used term *active learning*, which covers a broad array of techniques in STEM education. From a CogPsy perspective, the focus is on the underlying mechanisms behind active learning, which is seen as effective because top-down processing promotes strong memories, requires executive function, and makes the task more meaningful (Freeman et al., 2014).

Despite these differences, both DBER and CogPsy researchers appreciate the potential alignment between the objectives of their research as well as the potential benefits from the two groups forging collaborations.

Benefits of DBER/CogPsy Collaborations for the DBER Community

DBER could benefit from the proven research methodologies utilized in CogPsy. For example, counterbalancing, a staple in CogPsy experimental design that includes all possible orders of a treatment, is not common in DBER experiments. If DBER researchers were interested in improving learning in a discussion section of a large introductory course, they might add the study of worked solutions to their current practice of having students solve problems. Rather than have students first study worked solutions to problems then practice problem solving, the researcher could evaluate the impact of having two groups of students undergo the interventions in both orders. Furthermore (and unrelated to counterbalancing), assessing problem solving performance immediately after the intervention as well as a week following would reveal if there is a delayed effect (e.g., more forgetting with one order of the intervention versus the other). Numerous examples of such studies exist in the CogPsy literature (e.g., Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Paschler et al., 2007; also, an internet search of the term *desirable difficulties* produces additional information and references).

Similarly, DBER graduate students could benefit from DBER/CogPsy collaborations since training in experimental design and data analysis techniques would complement their training in content knowledge in the discipline, which is a strength of DBER programs.

Such training would help DBER researchers design research studies and analyze the data collected, whether they be carefully controlled lab-based studies with random assignment or quasi-experimental designs within the messy environment of the classroom. Over time, such training could extend the existing range of research techniques available in DBER.

Benefits of DBER/CogPsy Collaborations for the CogPsy Community

CogPsy researchers are interested in describing generalizable workings of the mind (e.g., learning, memory, perception, and reasoning), meaning the types of tasks used in experiments are of secondary importance. In contrast, the type of task matters greatly to DBER researchers, given their goal of affecting student learning in the context of a discipline. For example, a memory experiment using English-Swahili word pairs (Karpicke & Roediger, 2008; Pyc & Rawson, 2010; Vaughn, Dunlosky, & Rawson, 2016) would be relevant to CogPsy but not DBER researchers. Extending CogPsy research to more complex tasks, as required in the STEM disciplines, would allow CogPsy researchers to test the limits of their theories in complex domains that require substantial prior knowledge.

It is also the case that the broad impact of CogPsy findings would increase should they prove useful in STEM education, thus opening the door for further collaborations. One example is the *testing effect* which shows that long-term memory improves when at various times during learning, students are asked to retrieve information through testing with appropriate feedback. Collaboration with DBER researchers may demonstrate improved long-term retention of STEM concepts and problem-solving procedures if sufficiently controlled or if quasi-experimental studies of the testing effect using complex STEM tasks were conducted. Another CogPsy finding that could be tested collaboratively with DBER researchers is *massed* versus *spaced* practice. STEM education primarily uses massed practice, wherein material is introduced linearly in courses and homework has students practice only the material that has been recently taught. Findings from CogPsy indicate that spacing practice over longer periods, such as having homework and exams contain problems from *all* previously covered material, pays substantial dividends for long-term retention of the learned material. (See Dunlosky et al., 2013; Paschler et al., 2007 for overviews; also, an internet search of the term *spacing effect* will provide additional information and references). Testing how readily these ideas transfer to STEM classrooms would be strengthened by collaborations among DBER and CogPsy researchers.

Benefits That Cross DBER and CogPsy

Both communities could benefit from exploring ways of improving STEM instruction by applying learning principles gleaned from carefully controlled CogPsy experiments to the messy environment of the classroom. Adapting learning principles for effective classroom practices could benefit from a cognitive psychologist's deep knowledge of the conditions under which a learning principle applies *and* the DBER researcher's deep understanding of STEM content and context, that is, pedagogical content knowledge (e.g., Gess-Newsome & Lederman, 1999). Global benefits of such endeavors include improvement of motivation, learning and retention of students in STEM fields, and the intellectual challenge of implementing theoretical knowledge in real-world contexts.

Research into how students learn the engineering design process would also offer a unique context that would benefit both communities. Engineering design is a profoundly complex task that engages students not only in convergent thinking, such as applying knowledge to solve known problems, but also in divergent thinking, such as generating new knowledge and solution paths (Dym, Agogino, Eris, Frey, & Leifer, 2005). Most CogPsy research has focused on convergent thinking tasks such as recall of facts, so collaborations would provide CogPsy researchers with a fertile new research direction to test and expand their theories. Given the complexity and multifaceted nature of design, the engineering education community would benefit from a diversity of perspectives on the challenges involved.

In addition, both disciplines could benefit by exploring the larger issues of data sharing and replication (National Science Foundation, 2016), topics that are receiving increasing attention in both disciplines. While data sharing has the potential to help build cross-disciplinary collaborations, considerable work is needed to communicate standards of data collection and storage as well as developing means of data provenance. Replication is also an issue being considered in both disciplines (Benson & Borrego, 2015), and developing a set of common standards and expectations for replication studies could improve the merit and impact of work in both fields.

Challenges Ahead

The collaborations proposed here are not without challenges (McDaniel et al., 2017). One concern is related to the criteria currently used in tenure, promotion, and rewards in higher education, all of which are structured around departments with long-established traditions for evaluating scholarly work. How to evaluate collaborative work across DBER-CogPsy boundaries – particularly challenges in evaluating publications in journals that are unfamiliar to a department and difficulties in having senior scholars outside the department serve as credible evaluators for tenure or promotion – would have to be addressed. On the other hand, external funding opportunities abound in STEM education, making a DBER-CogPsy partnership attractive for the pursuit of large projects. Yet another concern is the long-term employment opportunities for a post doc from one research tradition (DBER or CogPsy) who would like to engage in a project in the other tradition; it is possible that experience outside the person's primary field will not be seen as valid to prospective employers. In addition, communication between the two communities also remains a challenge. There is no natural mechanism for a DBER researcher and a CogPsy researcher with common interests to meet or hear about each other apart from happenstance. Conferences and journals, which is where researchers learn about each other's work, are still largely built around disciplinary silos.

Final Thoughts

Despite the significant challenges to more collaboration between DBER and CogPsy researchers, there are significant benefits to both research traditions should the initial investment of time and effort be undertaken. The many examples of successful collaborations between these researchers demonstrate some possibilities, with the 34 attendees at the DBER-CogPsy conference mentioned earlier being primary examples, as well as centers forming at universities such as Kent State (Science of Learning & Education Center), Washington University in St. Louis (Center for Integrative Research on Cognition, Learning and Education), and the Carl Weiman Science Education Initiative (CWSEI) at the University of British Columbia. One suggestion is for the pioneers in such collaborations to document and publish models for others to follow. A university that already has DBER and CogPsy researchers collaborating could build a small set of "core courses" for graduate students in both disciplines to learn about each other's discipline, as well as experimental and data analysis traditions. Ways to do this can be as simple as attending a seminar in a psychology or neuroscience department or inviting a colleague to lunch, or as involved as working with interested colleague to submit an NSF Professional Formation of Engineers: Research Initiation in Engineering Formation (PFE:RIEF) proposal. Many other ideas can be found in the final report of the DBER-CogPsy conference to help bridge the divide between these two disciplines (McDaniel et al., 2017).

Ultimately the question comes down to whom researchers in each community see as the primary beneficiaries of their work, with the recognition that research and education form a complex ecosystem where the concept of benefit often differs between faculty, teachers, students, policy makers, and administrators. This question of benefit, which is often framed as impact, is increasingly on the mind of policy makers as state and federal budgets become tighter. Advances in understanding how learning occurs need to translate into the complex environment of a classroom where this knowledge directly impacts student learning.

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