Maximizing undergraduate STEM learning: Promoting research at the intersection of cognitive psychology and discipline-based education research[1]

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Introduction

In recent years, improving undergraduate STEM education has become a national priority. A clear goal of this priority is to build an evidence base that informs improvements and transformations in STEM education. This has spurred the development of a constellation of new disciplines that fit the moniker of discipline-based education research (DBER), such as physics education research, biology education research, and so on (Singer, Nielsen & Schweingruber, 2012). Because DBER has primarily been driven by grassroots efforts of faculty in the respective disciplines (e.g., individuals trained as biologists "switching" to studying teaching and learning of biology), much work in DBER has been done without clear connections or integration with fields that have a long tradition of studying teaching, learning, and thinking, such as cognitive psychology (CogPsy) and educational psychology. In parallel, many cognitive psychologists are focusing their efforts on research and theory that is inspired by educational issues and learning in authentic educational contexts. Yet, much of this work has not been directly connected to particular discipline-based content or learning challenges addressed by DBERs. This lack of cross-talk between DBER scholars and cognitive psychologists has meant that potentially useful teaching and learning strategies remain unknown/unused by most STEM faculty (see, for example, Dunlosky, Rawson, Marsh, Nathan & Willingham, 2013; NCER, 2007). To better understand the issues that discourage forging such connections, to formulate recommendations for mitigating those issues, and to explore potential avenues for stimulating DBER-CogPsy collaborations, we (Mark McDaniel from Washington University in St. Louis and Jose Mestre from the University of Illinois at Urbana-Champaign) convened a meeting of 34 cognitive psychologists and DBER scholars with support from the NSF (September 16-17, 2016).

The conference had no formal talks or presentations. Instead, participants were divided into smaller groups to facilitate discussion of broad issues related to increasing CogPsy-DBER collaborations and communication. This report is organized around two broad themes that initiated the discussions: standards for research and evidence and CogPsy-DBER collaborations. Below we describe each theme in greater detail and present recommendations for next steps aimed at improving CogPsy-DBER interactions, including how NSF can use this document in its strategic planning.

Research Methodologies and Standards for Evidence

DBER research is often conducted in classrooms or other naturally occurring learning environments, necessitating quasi-experimental, non-experimental, and correlational techniques.

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In contrast, CogPsy research is typically conducted in the laboratory using experimental techniques and then transported to the classroom in ways that also make use of experimental designs and methods (e.g., within-subjects designs to examine the influence of retrieval practice or interleaving on learning). These distinctions raise the possibility that different standards of evidence are used by DBER and CogPsy researchers, which might pose barriers to CogPsy-DBER communication and collaboration. Discussion on this issue, rather than revealing a wide schism in absolute standards for evidence, resulted in a shared framework that acknowledged the need for a range of designs, methods, and evidence to inform and guide STEM education (see Schneider, Carnoy, Kilpatrick, Schmidt, & Shavelson, 2007, for a similar conclusion).

A major feature of this framework was that *standards reasonably differ because of context and research purpose.* Regarding purpose, DBER and CogPsy scholarship have a range of stakeholders who influence the goals and outcomes of the research. For example, DBER scholars often aim to influence colleagues who are instructors. Evidence that is qualitative, informal, or drawn from small samples is often sufficient to motivate colleagues to make changes to their instruction, which can then be iterated and refined based on measures of effectiveness. Because the objective of a noteworthy proportion of DBER scholarship is to improve classroom practices, some DBER scholars may opt not to adopt methods that constrain that opportunity in classrooms. For example, they may want to change a classroom intervention in real-time to improve student learning, even if this undermines the design of a study. Their research methods will necessarily be more iterative than those that commonly are adopted by CogPsy researchers doing laboratory studies.

Because much DBER scholarship takes place in classrooms, studies are tied to the academic calendar and are limited by the available sample (e.g., enrollment in a course). Thus, DBER scholars may be more willing to make inferences about teaching and learning based on smaller sample sizes, fewer iterations of data collection, or with less careful controlling for all of the relevant variables (e.g., nesting of students within courses within institutions). However, DBER and CogPsy researchers alike acknowledge that this is not sufficient for drawing causal conclusions. Thus, the standards for interpretation are not different.

A notable portion of DBER research has focused on *how to apply* research-based strategies to improve disciplinary learning for undergraduates, whereas CogPsy studies generally focus on illuminating the processes or underpinnings of effective practices. One might argue that this DBER objective does not necessarily require or allow the same level of control that characterizes the CogPsy objective. As an example, a DBER scholar might be 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 (direct effects of retrieval, increased metacognitive accuracy, better student study habits). In contrast, a CogPsy researcher would proceed with more controlled, experimental investigation to identify the causes of this effect and thus make its subsequent application more precise, which may only be possible in a laboratory setting.

A second distinction between DBER and CogPsy that may result in differing evidence is that the target outcomes may differ. In CogPsy laboratory studies, the outcome metrics or measures are typically focused on learning or retention of knowledge. By contrast, in DBER studies, the focal measures often expand to include motivation, usability, affect, and longer-term behavior (e.g., enrolling in subsequent STEM courses, completing a STEM major). Moreover, the validity of some outcome measures in authentic settings, such as instructor-constructed exams or course grades, may be hard to gauge. The exam validity issue is a very difficult problem to solve because the validation process for an exam is more arduous than one would expect a faculty member to undertake. In recognition of this problem, scholars in some disciplines DBERs have focused on developing and validating measures of conceptual understanding that can be applied across classrooms (e.g., concept inventories) as well as other systematic methods of analyzing classroom-level data (e.g., rubrics).

A third complicating factor is that operationalization of broadly-defined constructs can differ not only across CogPsy and DBER communities but also within these communities. For instance, a central construct in the literature is that of "active learning," yet there is wide variability in what is meant by active learning, even within a single article. Standards of evidence are partly determined by the alignment of the operational definitions and the construct of interest.

In conclusion, there do not appear to be exclusively different standards of evidence across CogPsy and DBER, but rather different methodological designs better suited to the research questions, objectives, and contexts on which each group focuses. DBER and CogPsy researchers thus need to carefully define the questions under study, the variables, and the outcomes being explored to ensure productive and sustainable collaborations.

What is the Role of Observational Research and the Evidence Derived from those Studies?

The above section underscores the point of agreement that carefully controlled experiments are not always best suited for DBER contexts and objectives. One emergent feature of a DBER-CogPsy shared framework is that it would incorporate a range of methods and evidence. In particular, there is agreement that observational, correlational, and quasi-experimental studies hold value for particular contexts and objectives, such as for:

1. Stimulating further development of particular lines of research and providing a foundation for replication at other institutions, perhaps with more experimental designs.
2. Accumulating a preponderance of evidence collected with observational designs. The weight of convergent observational results might be deemed sufficient to make pedagogical recommendations. This approach may be necessary, as it is not always possible (or even often possible) to conduct highly controlled studies.
3. Ultimately, designing carefully controlled studies that explore causal claims from insights gleaned from observational designs (see Schneider et al., 2007, for amplification).

Going Beyond a Single Research Standard: Developing a Common Ground

The strong consensus among the DBER and CogPsy researchers at the meeting was that it would be misguided to try to establish one standard of evidence. Insisting on one standard is likely to reinforce existing *perceived* gaps between DBER and CogPsy research. Instead, we recommend appreciating the multiple objectives of DBER and CogPsy-based education research and recognizing that methods are appropriate to the extent that they align with those objectives. Our discussions resulted in a "blueprint" for how to create shared standards for evidence. This blueprint identified some core "action items" that merit more in-depth discussion or focus, perhaps through initiatives from NSF to support working meetings of groups of DBER and CogPsy researchers. The action items include:

1. Shared standards should focus on
(a) Making sure that the method suits the purpose of the research and aligns with the claims made. Doing so might preclude, for example, the types of in-the-moment-instructional-decision studies that broadly explore the promise of instructional interventions rather than comparing the relative effectiveness of two different pedagogical approaches.
(b) Developing expectations for replicability of key findings. Findings determined to be key should meet standards of replication to provide a convincing evidence base.
(c) Establishing guidelines for asserting generalizability. The idea is that conclusions about the applicability of particular findings could be considered within consistent guidelines (e.g., Common Guidelines for Education Research and Development, 2013).
2. Ideally, there would be community agreement not on a singular "gold standard" but on a set of gold standards for particular designs in specific situations, and more generally on a set of criteria for selecting certain types of studies for certain types of situations. One complication associated with this kind of endeavor is that there are differences in non-experimental study qualities. For example, descriptive studies are often used in the beginning of a research line within a domain, but the standards for these types of studies may change as the research line develops (as specified in the IES and NSF Common Guidelines, 2013)
3. Research reports would be expected to provide complete and explicit descriptions of interventions, controls, and definitions of key constructs. The idea is that these descriptions will allow researchers and educators to effectively reconstruct the intervention, understand the control(s), and be able to articulate the key constructs.
4. Journals could reinforce explicit standards for observational and quasi-experimental studies drawn from recent sources (e.g., Schneider et al., 2007). There also may need to be more explicit standards for reviewers. Perhaps journals ought to require a "limitations section" for these articles to discuss the limitations of various interpretations.
5. DBER journals could perhaps add a section for research studies that focus on novel or forward looking issues but have less rigorous design. These articles would have lower standards of evidence with tempered claims, but would provide opportunities to later test promising findings with more carefully crafted methodologies.

CogPsy-DBER Collaborations

Except for small pockets of CogPsy-DBER collaborations nationwide, with many of those occurring among the attendees, CogPsy-DBER collaborations are not common. Yet, the potential benefits of such collaborations are significant. For example, our discussions pointed out that theories in cognitive psychology are often elegant and rigorously expressed, yet when one tries to apply them to real-world learning situations they often appear brittle and under-specified. Further, when grappling with STEM disciplinary knowledge in extending theories, cognitive psychologists often realize that their original conceptualizations of understanding were too simplistic or unnecessarily restrictive. Discipline-based education researchers could also benefit from testing psychological theories within their disciplines. Much of our discussion centered on ways to increase CogPsy-DBER collaborations not only to enhance our understanding of cognitive functioning along the STEM novice-to-expert dimension, but also to improve our ability to design and refine instructional strategies for effective and efficient learning. Below, we organize these discussions in terms of obstacles to collaborations and how they can be mitigated, and opportunities for collaborations and how they can be enhanced.

What Are the Obstacles to CogPsy-DBER Collaborations and How Can They Be Overcome?

Communication between the CogPsy and DBER communities was identified as a major problem. CogPsy researchers publish almost exclusively in psychology journals and DBER researchers publish in their own disciplinary education journals (e.g., *Journal of Chemical Education, Physical Review: Physics Education Research, CBE-Life Sciences Education*). Most CogPsy researchers do not read DBER journals, and vice versa. In addition, DBER researchers tend to stay within their disciplines rather than reading DBER journals outside their disciplines, resulting in lack of communication even within the DBER community. This is true of graduate training in the various fields as well, with emerging Ph.D.s having little knowledge of the major issues and findings from the other disciplines. Conference participants believe that lack of common knowledge among DBER and CogPsy scholars discourages collaboration—for example, the term “learning” can have very different meanings in the two communities. The same is true within DBER disciplines. DBER participants echoed the need for enhanced communication among DBER scholars. A meeting that followed ours, sponsored by the American Association for the Advancement of Science (AAAS) and the Association of Public and Land-Grant Universities (APLU) is exploring the possibility of forming a STEM DBER alliance to promote cross-DBER communication and collaboration.

A number of suggestions emerged to improve this situation, some easier to accomplish than others. One suggestion was to create a list of 100 seminal DBER and CogPsy articles that should be common knowledge across these two fields, which could then be part of Ph.D. training. Creating more opportunities for CogPsy and DBER researchers to learn about each other’s interests was offered as a means of forging collaborations, but no natural mechanism for doing this currently exists (other than rare conferences like this one). The creation or co-option of a cross-cutting CogPsy-DBER journal focusing on the improvement of STEM teaching and learning was viewed as an excellent way to both bridge the two fields and increase communication between them, as was the creation of a “newsy” section in existing DBER and CogPsy journals where “news and views across CogPsy and DBER” could be highlighted.

Another obstacle voiced was that the types of tasks that CogPsy scholars use in their cognitive experiments are often viewed by DBER scholars as not directly applicable to STEM education. The goal of much CogPsy research is to extract broad learning principles, and CogPsy scholars view the content matter used in such research as secondary. On the other hand, DBER researchers view their content matter as primary. For example, they perceive that memory experiments that ask participants to memorize word lists, learning experiments that train participants to recognize paintings by particular painters, or experiments on the “testing effect” that use factual information as the content of the tests as far removed from their attempts to teach high-level reasoning and problem solving to students. It was pointed out during the conference that many CogPsy experiments *could* draw on content matter from the STEM disciplines and even focus on content matter that is highly valued and seen as pivotal by DBER scholars (e.g., learning of high-level concepts or problem solving). Yet, the lack of communication and common knowledge across CogPsy-DBER has precluded this.

Members of the CogPsy community at the conference noted other contextual factors that limit their collaborations with DBER scholars, especially at major research universities. Among these was the perception among many CogPsy faculty, psychology department heads, and tenure and promotion committees that DBER journals are sub-par in terms of the experimental rigor expected in psychology. Therefore publications resulting from CogPsy-DBER collaborations in DBER journals by psychologists often “do not count” as heavily, or at all, in merit reviews or tenure and promotion decisions. Another issue is that psychology department heads do not know distinguished DBER faculty who could serve as references for tenure and promotion for cognitive psychologists who collaborate with DBER scientists. It is important to state that this phenomenon is common when traditional disciplines stray from the norm and typically becomes less significant as time passes. One of us (JPM) made the shift from physics to physics education research (PER) while working within a physics department almost 40 years ago at a time when there were literally only a handful of PER researchers working in research universities in the U.S. Initially this work was viewed as “education” and “not physics” by his colleagues, but eventually he was awarded tenure and promotion within that department. Historical accounts of the growth of various DBER fields can be found in papers commissioned by the National Research Council for the DBER report (see:
http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_072579.pdf,
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A number of factors can help improve this situation. Among them are having DBER journals publish articles with methodologies common in psychology journals, and inviting CogPsy scholars to publish articles in DBER journals. In addition, white papers by disciplinary organizations, such as the Association for Psychological Science, the Psychonomics Society, and the American [Biology, Chemical, Physical] Societies, promoting the value of CogPsy-DBER collaborations, as well as policy statements about the legitimacy of such research, help the political landscape and pave the way for meaningful progress. For example, policy statements by the American Physical Society (see: https://www.aps.org/policy/statements/99_2.cfm) and the American Chemical Society (see: https://www.acs.org/content/dam/acsorg/about/governance/committees/education/statement-on-scholarship.pdf) had important impacts within those communities. Another suggestion was that professional organizations keep lists of prominent scientists who are capable of serving as informed reviewers in tenure and promotion decisions. Four other recommendations that emerged include: creation of awards recognizing significant CogPsy-DBER collaborative efforts; creation and on-going support of centers specifically designed to facilitate CogPsy-DBER collaborations, such as the Center for Integrative Research on Cognition, Learning and Education (CIRCLE) at Washington University in St. Louis; creation or co-option of a joint CogPsy-DBER journal; and creation of a DBER society that bridges the various STEM disciplinary efforts as mentioned above.

Opportunities for Collaborations and How Those Can Be Enhanced

Given that CogPsy and DBER are independent fields, each with diverse, but confined subfields, there is no natural mechanism for enhancing collaborations. There are a number of incentives and actions that would help achieve this goal. With respect to doctoral training, CogPsy and DBER scholars at universities where there are already collaborations could work toward generating a small, common core of graduate courses. Those courses would help create a common lexicon as well as shared methodologies, norms, and standards of evidence. The reciprocal benefits of overlapping, joint graduate training across CogPsy and DBER would also allow scholars from CogPsy to consider using tasks of interest to DBER scholars in CogPsy experiments, and allow DBER scholars to use experimental methodologies that expose cognitive functioning or explore causal relationships, ultimately improving STEM instruction.

At the faculty end of the spectrum, scholars in CogPsy looking to expand the range of topics and tasks used in experiments could hire DBER postdocs, and DBER scholars wishing to explore new methodologies in STEM learning and teaching could hire CogPsy postdocs. This cross fertilization could pave the way for exploring causal mechanisms in learning and performance that could in turn be used in the design of effective instructional strategies. Another option would be to create a "scholar matching website," similar to dating services like match.com, where CogPsy and DBER scholars could find potential collaborators who share mutual interests. Scholars would fill out "profiles" stating their expertise, interests, and desired collaborations. The site could attempt to match scholars with similar interests, and perhaps make available an online forum for "speed dating" where scholars could quickly meet other scholars and discuss mutual interests.

Professional organizations could also promote collaborations. For example, journals from CogPsy and DBER professional organizations could appoint scholars from other disciplines as senior members of their editorial boards. These senior scholars would not only learn about relevant research being conducted in the other's discipline but also help play matchmaker by connecting scholars with common interests. At their national meetings, CogPsy and DBER professional organizations could also sponsor invited sessions that showcase CogPsy-DBER collaborations.

Finally, federal funding agencies, like the National Science Foundation and the Institute for Education Sciences, are in a position to provide strong incentives for promoting CogPsy-DBER collaborations. Funding from these agencies not only supports research, it also brings prestige associated with funding from these agencies. For example, the NSF CORE program (EHR Core Research, ECR, Fundamental Research in Science, Technology, Engineering and Mathematics [STEM] Education) was developed with such collaborations in mind, and currently funds such work. The NSF EHR IUSE program (Improving Undergraduate STEM Education) also encourages collaborative research and development to improve undergraduate teaching and learning. At a somewhat smaller scale, NSF could also promote collaborations by funding sabbaticals where CogPsy or DBER scholars spend a semester or year working with a scholar from the other discipline on specific projects of mutual interest.

Core Issues and Recommendations

In this section, we distill the core issues that emerged from our discussions and summarize our recommendations for addressing these issues. We firmly believe that recommendations from this meeting should be incorporated into the NSF strategic plan.

***Core issue 1*: Establishing the legitimacy of DBER/CogPsy collaborative work.** Establishing the legitimacy of DBER/CogPsy collaborative work remains a challenge both in the DBER and CogPsy communities.

- **Association for Psychological Science (APS) and Psychonomic Society to release a white paper stating the importance of DBER work and recognizing it as a part of psychological science.**
  DBER scholars in chemistry stated that American Chemical Society's release of a white paper recognizing DBER work in chemistry significantly changed their peers' perception of DBER work, as did a policy statement by the American Physical Society explicitly valuing and supporting physics education research within the physics community. We request that APS craft and release a similar white paper stating the importance and value of psychologists' collaboration with DBER scholars. It would be ideal if this effort could be paired with an invited paper in a high impact journal, such as *Perspectives on Psychological Science*.

- **Professional societies develop a list of distinguished individuals who can write a letter evaluating a candidate's DBER work when DBER/CogPsy scholars are facing tenure or promotion.**
  One of the most important factors in tenure and promotion review is the quality of letters from outside the institution stating the impact of the applicant's work. However, distinguished scholars in the applicant's specific field are often unable to comment on the value of DBER work. We request that professional societies create and maintain a list of distinguished scholars who can write a letter evaluating applicants' DBER work.

- **Professional societies collaborate to create an award.**
  An award from professional societies can provide a valuable line on a scholar's resume. We request professional societies to create awards recognizing collaborative efforts between DBER and CogPsy scholars. The awards do not have to include an honorarium. Creation of awards is an inexpensive way of promoting collaboration.

- **Professional societies collaborate to create a journal.**
  A new journal issued collaboratively between DBER and CogPsy professional societies can create a unique outlet for collaborative work that can be regarded highly by both the DBER and CogPsy communities. However, creation of a new journal is cost and labor

intensive. Other possibilities include publishing CogPsy-DBER collaborative research in existing venues, such as AAAS's *Science Advances*, or in existing DBER and CogPsy journals.

- **Encourage special issues in journals.**
  Another feasible way of increasing outlets for collaborative work is to encourage journals to publish special issues devoted to articles featuring collaborative work.

***Core issue 2*: Promoting DBER/CogPsy collaborative work.**

The following recommendations are intended to increase CogPsy-DBER collaborations.

- **CogPsy and DBER scholars collaborate to establish guidelines for the types of methodologies needed in different study contexts**.
  Study designs and methods should fit contextual constraints. The more stringent the goals of a study (e.g., attributing causality), the more care needs to be given to experimental design. A working group tasked to construct these guidelines might be funded by NSF, perhaps starting with the document, *Common Guidelines for Education Research and Development* (https://www.nsf.gov/pubs/2013/nsf13126/nsf13126.pdf), jointly published by NSF and IES, and expanding these Common Guidelines to include CogPsy perspectives.

- **Establish CogPsy-DBER collaborative centers, such as CIRCLE at Washington University in St. Louis, Science of Learning and Education (SOLE) at Kent State, and the Center for University Educational Scholarship (CUES) at the University of Arizona.**
  Establishing centers focused on collaborative work is a great way to encourage and support CogPsy-DBER collaborations. However, we also recognize that this is an expensive solution that requires securing significant amounts of funding. A cost-sharing initiative between universities and NSF or IES could leverage this funding challenge.

- **Federal funding agencies, such as the NSF, encourage CogPsy-DBER collaborations through existing programs.**
  As argued earlier, funding is a great incentive to spur collaborations, and is also used by most universities to gauge research quality and productivity in tenure, promotion, and merit pay decisions. Through programs such as NSF's IUSE and CORE, additional collaborations could be fostered.

- **Encourage employment of CogPsy scholars in DBER positions and vice versa.**
  DBER positions, often at the postdoc level, mostly require a discipline-specific degree. For example, a physics PhD is required for physics education positions. However, this requirement often eliminates opportunities for CogPsy scholars to penetrate into DBER fields. Increasing the number of CogPsy scholars in these positions can be a great start of DBER/CogPsy collaboration as well as sharing of knowledge in classroom research in both fields.

- **NSF establishes a program housed within specific units in the sciences, engineering, and the behavioral sciences to fund sabbaticals for CogPsy and DBER scientists to collaborate on research of mutual interest**.
  Applications for such sabbaticals would be evaluated by program officers from the two collaborating disciplines with evaluation criteria based on quality of work proposed and likelihood of deliverables (e.g., journal articles, curricular reforms).

Core issue 3: Enhancing communication between DBER and CogPsy

Some of the recommendations under Core Issues 1 and 2 already address enhancing communication between DBER and CogPsy. We offer additional recommendations for enhanced communication here.

- **Incorporate CogPsy perspectives into STEM (DBER) graduate training, and STEM-DBER perspectives into CogPsy graduate training.**
  STEM scholars often are simply not aware of CogPsy concepts and methodologies, and the dissemination of the knowledge should happen early rather than later. Offering graduate courses for STEM Ph.D. students on topics, such as applying psychological principles to STEM classrooms, or research designs and methodologies in classroom research, or applying psychological principles in the study of students' problem solving or conceptual understanding, would be a great way of achieving this goal early in STEM scholars' career. Further, it may encourage more STEM scholars to conduct high quality DBER research later in their career. All of the above also goes in the opposite direction, such that CogPsy training could draw from DBER expertise.

- **Collaborative Research Courses at advanced undergraduate/graduate level for CogPsy students: CogPsy students work with STEM instructors to conduct in-class assessments and experiments.**
  Pairing up CogPsy students with STEM instructors to conduct semester-long, collaborative research projects would benefit both disciplines. Models for this exist, for example, at UCLA (reported by Elizabeth Bjork at our conference).

- **Create a list of 100 seminal DBER and CogPsy papers.**
  Establishing common knowledge is necessary for communication and collaborations among CogPsy and DBER scholars. One way to achieve this is to select 100 (or any other appropriate number) DBER and CogPsy papers that are seen by the scholars in each field to be exemplary in areas such as methodology (both lab-based and classroom-based), seminal findings, and curricular adaptations of research-based instructional strategies.

- **Create a mechanism whereby DBER/CogPsy scholars can find out about each other's interests (i.e., a "scholar matching" website).**
  There currently exist very few opportunities that can connect DBER and CogPsy scholars. Funding an interactive online site, similar to "dating" websites, would enable CogPsy and DBER scholars in learning about each other's work and forming collaborations that suit their mutual interests.

- **Listserv/social media/digest**
  Highlighting up-and-coming DBER as well as CogPsy papers through email (listserv), a website (social media), or a release from a journal/professional society (digest) is an inexpensive way to let scholars in DBER and CogPsy community know who in the other field is conducting the type of research they are interested in.

Core issue 4: Uniting DBER scholars from different disciplines

Although this issue may not directly pertain to collaboration and communication *across* CogPsy and DBER, many DBER scholars echoed the need for enhanced communication *among* DBER scholars in different disciplines. Uniting the DBER communities will also help in coming up with a shared agenda that may lead to more efficient use of resources. Below are recommendations to improve the communication among the DBER disciplines.

- **Establishing a professional society for DBER scholars across disciplines.**
  Establishing a cross-disciplinary DBER professional society would benefit the entire DBER community through sharing of knowledge, establishing shared agenda, and consolidating efforts. Work currently under way by AAAS and APLU is leading toward such a STEM DBER alliance.

- **Professional societies collaborate to create a journal.**
  Similar to the recommendation under Core Issue 1, professional societies in DBER in different disciplines could create a multi-disciplinary journal to serve dual purposes: (1) provide a model of DBER research across the disciplines, and (2) provide highly regarded DBER research output. Recently a journal was created by the Psychonomic Society, *Cognitive Research: Principles and Implications*, with the express purpose of showcasing use-inspired basic research growing out of hypotheses about real-world problems.

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Appendix: Attendees at the Conference and Bio-Statements

Elizabeth Ligon Bjork is a Professor of Psychology at the University of California, Los Angeles, where she has chaired UCLA's Academic Senate and received UCLA's Distinguished Teaching Award. Her main area of research is the study of human memory, in particular, the role of inhibitory processes—such as those underlying goal-directed forgetting and memory updating—in making the human memory system adaptive. Recently, in research supported by a collaborative James S. McDonnell Foundation Award, a focus has been on how cognitive principles discovered in the laboratory can be applied to enhance instructional practices and self-directed learning. One theme of this research is how best to use "desirable difficulties"—such as testing, particularly multiple-choice testing—not only to enhance the long-term retention and transfer of both tested and related information but also to potentiate the initial study and learning of such information. She is an elected member of the Society of Experimental Psychologists, a Fellow of the Association for Psychological Science and the Western Psychological Association, and has served on Editorial Boards for *Perception & Psychophysics* and *Memory & Cognition* and on Review Panels for NIMH and the NSF REESE program. Most recently, with Robert A. Bjork, she is a joint recipient of the James McKeen Cattell Fellow Award from the Association of Psychological Science, a lifetime achievement award for outstanding contributions to the area of applied psychological research.

Robert A. Bjork is Distinguished Research Professor in the Department of Psychology at the University of California, Los Angeles. His research focuses on the interactions of forgetting and learning that uniquely characterize how humans learn and remember; on the degree to which learners understand or misunderstand such dynamics; and on the implications of such research for the optimization of instruction and self-regulated learning. He has served as president or chair of the American Psychological Society (APS); the Psychonomic Society; the Society of Experimental Psychologists; UCLA's Department of Psychology; and of a National Research Council Committee on Techniques for the Enhancement of Human Performance. He also served as Editor of *Memory & Cognition* and *Psychological Review*, Co-editor of *Psychological Science in the Public Interest*, and he chaired the Council of Editors of the American Psychological Association. He is a recipient of UCLA's Distinguished Teaching Award; the American Psychological Association's Distinguished Scientist Lecturer and Distinguished Service to Psychological Science Awards; the Society of Experimental Psychologists' Norman Anderson Lifetime Achievement Award; and, together with Elizabeth Bjork, the James McKeen Cattell Award from the Association for Psychological Science. He is a Fellow of the American Academy of Arts and Sciences.

Myles Boylan has been a Program Director at the National Science Foundation (NSF) since 1996 within the Directorate for Education and Human Resources. He has worked in many education programs in that directorate. In recent years he has co-led TUES (Transforming Undergraduate Education in STEM) and WIDER (focused on catalyzing institution-wide implementation of evidence-based teaching methods). After these two programs were coalesced into a broader program titled "Improving Undergraduate STEM Education (IUSE)" in 2014 he has led this new program in its EHR version: IUSE: EHR. Myles' doctoral work was in industrial economics. He held a variety of academic appointments before joining the NSF in 1984. His academic research focused on the process and diffusion of technological innovation in private industry and he continues to work through NSF to accelerate the diffusion of proven teaching methods and institutional change

Sara Brownell is a neuroscientist turned full-time education researcher, who teaches undergraduate biology while studying biology education at Arizona State University. Brownell's interests in undergraduate biology education are broad, but her current work focuses on three main avenues. She is investigating the impact of undergraduate research experiences on students, specifically students enrolled in course-based research experiences. She is developing a programmatic assessment for biology majors that focuses on the core concepts of biology. She is also exploring issues related to access and equity in undergraduate biology, specifically the experiences of women, religious students, and LGBTQIA students.

Sarah Brookhart was named Executive Director of the Association for Psychological Science (APS) on September 1, 2015. Prior to assuming the post of Executive Director, Brookhart served as APS Deputy Director for 13 years. Brookhart has been with APS since 1990, when she was hired as APS's first Director of Government Relations, and she has been instrumental in shaping the organization's growth and impact particularly in public policy and public outreach. She became APS's first Director of Policy and Communications in 1997. Brookhart also serves as Publisher of the *Observer,* the Association's monthly magazine and as an *ex officio* member of the APS Board. While the majority of Brookhart's professional career has been in psychological science advocacy and outreach, she worked on Capitol Hill, in higher education and environmental science organizations, and as a freelance science writer and editor specializing in behavioral and social science research. Brookhart has a Master's degree in public policy from The George Washington University and a bachelor's degree in English from The American University.

Diane M. Bunce is Professor Emerita of Chemistry at The Catholic University of America where she was the Patrick O'Brien Chemistry Professor. As a visiting professor at the US Naval Academy in 2013-2014 and 2015-2016, she served in the Chemistry Department as the Kinnear Chair for the Physical Sciences. Her research deals with the mismatch between how we teach chemistry and the way the brain functions in learning. Her research includes studies of how long students can pay attention in lecture and how long students retain knowledge after exams. She is one of the original authors of the American Chemical Society's high school curriculum (ChemCom) and college-level curriculum for nonscience majors (Chemistry in Context). Diane is the founding assistant editor of the Chemical Education Research section of the *Journal of Chemical Education* and the co-editor and author for several chapters in the American Chemical Society's Symposium Books Nuts and Bolts of Chemical Education Research and Tools of Chemical Education Research. She is a Fellow of AAAS (American Association of Science) and ACS (American Chemical Society). In 2012, she was the recipient of the national American Chemical Society's George C. Pimentel Award in Chemical Education.

Andrew Butler is an associate professor in the Department of Education at Washington University in St. Louis. He earned a Ph.D. in cognitive psychology at Washington University in St. Louis in 2009 and completed a postdoctoral fellowship at Duke University. Dr. Butler is interested in the malleability of memory – the cognitive processes and mechanisms that cause memories to change or remain stable over time. More specifically, his research focuses on how the process of retrieving memories affects the content (e.g., events, specific details, narrative structure, etc.) and phenomenological characteristics (e.g., confidence, emotional intensity, vividness, etc.) of those memories. His program of research addresses both theoretical issues in cognitive psychology and practical applications to education and mental health. The broad aim of this research program is to gain a better understanding of how retrieval affects: memories held by individuals and those shared by groups (i.e. collective memories); memories for simple materials (e.g., word lists, facts, etc.) to more complex memories that are rich in sensory detail, emotion, and self-relevance, among other characteristics; and newly formed, episodic memories in contrast to well-learned semantic memories that have been integrated into the knowledge base.

Ellen M. Carpenter received a B.A. in Biology from Dartmouth College in 1983 and a Ph.D. in Neurobiology from the University of Chicago in 1988, where she worked with Dr. Margaret Hollyday on cellular regulation of neuronal growth. She was a postdoctoral researcher at the University of Utah, where she worked with Nobel Prize-winner Dr. Mario Capecchi on his studies examining gene regulation of embryonic development and patterning. From 1996 through 2016, Dr. Carpenter was as assistant, associate, and full professor in the Department of Psychiatry and Biobehavioral Sciences at the University of California Los Angeles. She also served as the Chair of the Neuroscience Interdepartmental Program and as the Director of Outreach for the Brain Research Institute at UCLA. Her research addressed transcription factor regulation and cell signaling in embryonic brain development and cell migration. She is presently a program director in the Division of Undergraduate Education at the National Science Foundation where she focuses on improving undergraduate STEM education, particularly biology education.

R. Alan Cheville received degrees in electrical engineering at Rice University, specializing in ultrafast optical spectroscopy. After postdoctoral work in ultrafast optoelectronics, he joined the faculty of Oklahoma State University in 1998. He continued his work on high speed THz optoelectronics—supported by funding from the Department of Energy, the Army Research Office, and the National Science Foundation including a CAREER award—in areas such as THz time domain spectroscopy of molecular vapors and flames, pulsed ranging, and optical tunneling. During his time at Oklahoma State University he slowly transitioned his research interests from optoelectronics to engineering education, with an initial focus on effectively integrating research-based pedagogies into engineering curricula in the areas of photonics and electromagnetics. He led a five year, $1.2M NSF-sponsored department-level reform project at OSU that sought to integrate relevant design experiences and mathematical competencies across the curriculum. Following the conclusion of this project, he served for two and a half years as the program director for engineering education in the National Science Foundation's Engineering Directorate. During this time he developed several funding programs, served as NSF liaison to a Federal working group on games, as well as on several internal working groups. He was recognized by the Director's Award for Program Management Excellence. He currently serves as chair of the Electrical & Computer Engineering at Bucknell University, an associate editor of IEEE Transactions on Education and the Journal of Engineering Education, and on several advisory boards. He is currently interested in engineering design education, engineering education policy, and the epistemology of engineering.

Michelene (Micki) Chi is Professor in the Mary Lou Fulton Teachers College at Arizona State University (ASU), and formerly a Professor in Psychology at both ASU and University of Pittsburgh. Her research focuses on developing theories and principles about learning and pedagogy that are applicable to all domains of science, then translating them into practice. She currently has three strands of work applicable to pre-college and college-level instruction in STEM. The first strand is a theory of active learning or engagement called ICAP. The second strand is a theory about emergence causality that explains the robustness of many science misconceptions across domains. The third strand is her discovery of a new paradigm for learning from online videos that overcomes the limitation of active learning practices in asynchronous online learning contexts. Dr. Chi has published widely, in both cognitive science and learning science journals, as well as in the Journal of Engineering Education. Her current Google citations exceed 35,700. Dr. Chi was elected to the National Academy of Education in 2010, and she received the Sylvia Scribner Award from the American Educational Research Association (AERA) in 2013, and the Wickenden Award from the American Society for Engineering Education in 2014 for the best published paper of the year. In 2015, she received the Thorndike Award from the American Psychological Association, and in 2016, the Distinguished Contributions to Research in Education Award from AERA. She was also elected to the oldest and most prestigious honorary societies –The American Academy of Arts and Sciences, in 2016

Alejandro de la Puente, Ph.D., is a AAAS Science and Technology Policy Fellow serving in the Directorate for Education and Human Resources, Division of Undergraduate Studies at the National Science Foundation. Prior to the AAAS fellowship, Alejandro was a postdoctoral research fellow at the Department of Physics in Carleton University. Alejandro is a spokesperson for Instituto Apoyo, a non-profit organization with a mission to design and implement educational solutions to promote inclusive social development in Peru. He is currently designing exploratory case studies to describe and assess the efforts institutions are making with the support of NSF funding to transform their teaching and learning environments to ones that support and scale-up he use of evidence-based teaching and learning practices across all STEM departments.

Erin Dolan is the Georgia Athletic Association Professor of Innovative Science Education in the Biochemistry & Molecular Biology Department at the University of Georgia. She teaches introductory biology and biochemistry, and her research group studies scalable ways of engaging students in science research and mentoring of undergraduate researchers in the life sciences. She has designed and led a wide range of professional development on active learning and mentoring, including intensive sessions for faculty to develop course-based undergraduate research experiences. She is principal investigator principal investigator or co-investigator on more than $6 million in grants, including one for CUREnet, a network of people and programs integrating research experiences into undergraduate courses. She is also Editor-in-Chief of the biology education journal, *CBE – Life Sciences Education*.

Kevin N. Dunbar University of Maryland.

John Dunlosky is a Professor of Psychology at Kent State University, where he has taught since 2004. He has contributed empirical and theoretical work on metacognition and self regulated learning, and his current research focus is on discovering techniques that will improve students’ self-regulated learning and achievement across the lifepsan. Dr. Dunlosky is a member of the Governing Board of the Psychonomics Society, a fellow of the Association for Psychological Science, a founder of the International Association for Metacognition, and co-authored *Metacognition*, the first textbook on the topic.

Diane Ebert-May is a Professor in the Department of Plant Biology at Michigan State University. She provides national and international leadership in biology education research and teaching. Ebert-May's lab group developed and tested a model for professional development using inquiry-based, learner-centered teaching. They continue to investigate the longitudinal impact of transformed biology courses on undergraduates' use of scientific practices (e.g., models, arguments, working with data, and narratives) to learn the core concepts in biology. Ebert-May led FIRST IV, an NSF-funded professional development program to help 201 postdoctoral scholars create and teach their first introductory biology course in preparation for their academic positions. Her book, *Pathways to Scientific Teaching (Ebert-May and Hodder eds, second edition in prep)*, is based on student-centered learning, inquiry-based instructional strategies, assessment and research. She teaches plant biology, introductory biology to majors in a large enrollment course, and a graduate /postdoctoral seminar on scientific teaching. Her plant ecology research continues on Niwot Ridge, Colorado, where she has conducted long-term ecological research on alpine tundra plant communities since 1971. She is a AAAS Fellow in the Biological Sciences. Her recent awards include the US Professor of the Year Award for Michigan from the Carnegie Foundation/CASE (2011), the Education Award from the American Association for Biological Science (2012), and University Distinguished Faculty (MSU 2012). She earned her BS from University of Wisconsin, Madison (Botany), MA and PhD University of Colorado (Ecology and Evolutionary Biology).

Noah Finkelstein is a Professor of Physics at the University of Colorado Boulder and conducts research is in physics education, specifically studying the conditions that support students' interests and abilities in physics – developing models of context. He is a PI in the Physics Education Research (PER) group, a co-director of CU's Center for STEM Learning, and co-director of the national Network of STEM Education Centers. He is involved in education policy serving on many national boards, is a Trustee of the Higher Learning Commission, a Fellow of the American Physical Society, and a Presidential Teaching Scholar. He currently serves as the inaugural Timmerhaus Teaching Ambassador for the University of Colorado system.

Regina (Gina) F. Frey is the Florence E. Moog Professor of STEM Education in Chemistry, the Executive Director of The Teaching Center, and the Co-Director of the Center for Integrative Research on Cognition, Learning, and Education (CIRCLE) at Washington University in St. Louis. Her work focuses on the development, implementation, and evaluation of collaborative-learning pedagogies, including Peer-led Team Learning (PLTL) and Process-Oriented Guided Inquiry Learning (POGIL), that improve student learning and help students transition to university-level STEM courses. In addition, she collaborates with CIRCLE co-Director Mark McDaniel, and faculty across the disciplines, to develop and evaluate teaching innovations that integrate cognitive-science research. She is highly involved nationally in The POGIL Project, and consults with universities across the country on incorporating active-learning strategies into STEM curricula.

Robert Goldstone is Chancellor's Professor in the Psychological and Brain Sciences department and Cognitive Science program at Indiana University. His research interests include concept learning and representation, perceptual learning, educational applications of cognitive science, decision making, collective behavior, and computational modeling of human cognition. He won the 2000 APA Distinguished Scientific Award for Early Career Contribution to Psychology, and a 2004 Troland research award from the National Academy of Sciences. He was the executive editor of Cognitive Science from 2001-2005. He has been elected as a fellow of the Society of Experimental Psychologists, the Cognitive Science Society, and the American Academy of Arts and Sciences.

Reshma Gouravajhala received her B.S. in Psychology from Villanova University in May 2015. She is a second-year Psychological and Brain Sciences graduate student in Mark McDaniel's Memory and Complex Learning laboratory at Washington University in St. Louis. Broadly, her research interests include educational applications of cognitive psychology (with a special emphasis on individual differences in learning), as well as category learning of both artificial and natural stimuli. She is currently working on projects relating to structure building, testing and transfer, essay writing (in collaboration with Elizabeth Marsh at Duke University), and rock category learning (in collaboration with Rob Nosofsky at Indiana University).

Andrew Heckler is an Associate Professor of Physics specializing in Physics Education Research (PER). He began his career in Cosmology and Astrophysics, but since 2002 he began working with other physicists and cognitive scientists to study physics learning. He is interested in the cognitive mechanisms that underlie student difficulties in physics, and investigating ways to help students overcome these difficulties. More specifically, he has worked on abstract/concrete representations, rapid processes that affect student answering, student understanding of physics diagrams, multi-concept problem solving, basic STEM skills, and the characterization of student understanding of several basic physics concepts. Additionally, he has developed a range of curricular materials and assessments, including for materials science engineering, introductory and intermediate physics, as well as materials for K-12 STEM teacher professional development.

Geoffrey L. Herman is a Teaching Assistant Professor in the Department of Computer Science and a Research Assistant Professor in the Department of Curriculum & Instruction. His research focuses on how students learn engineering and computing concepts and studying processes for creating systemic change in how engineering and computer science are taught in college settings. He has particularly focused on studying how students learn the concept of state in computing contexts and understanding how engineering diagrams and sketches affect students' cognition. Through the Illinois Foundry for Innovation in Engineering Education he has been working with faculty from across STEM to increase the use of evidence-based instructional practices and to scale those practices to increasingly large class sizes. He earned his Ph.D. in Electrical and Computer engineering from the University of Illinois at Urbana-Champaign as a Mavis Future Faculty Fellow and conducted postdoctoral research in the School of Engineering Education at Purdue University. He has been awarded several million in external funding to improve and study computer science and engineering education and has published over 60 peer reviewed articles.

Robert C. Hilborn is Associate Executive Officer of the American Association of Physics Teachers. He earned a bachelor's degree in physics (with highest honors) from Lehigh University and M.A. and Ph.D. degrees in physics from Harvard. After several decades as a physics faculty member at Oberlin, Amherst, and the University of Texas at Dallas, Hilborn joined AAPT in 2011. He had served as President of the American Association of Physics Teachers and on the Advisory Committee for the Mathematical and Physical Sciences Directorate of the National Science Foundation, on the Board of Advisors for the College of Science, Engineering, and Technology of Jackson State University, the American Association of Medical Colleges (AAMC) and Howard Hughes Medical Institute joint Committee on the Scientific Foundations for Future Physicians, and the AAMC MR5 MCAT review committee. More recently he has served on the Board of Advisors of the Penn Center for Minority-Serving Institutions. In the early 2000s, he served as chair of the National Task Force on Undergraduate Physics Programs, which led to the Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP) report. He is also the leader of the Physics and Astronomy New Faculty Workshops, funded by National Science Foundation, that have introduced over 1900 new physics and astronomy faculty members to the latest science pedagogy and the research that supports that pedagogy. Working with a team of K-12 teachers of physics, he led the American Association of Physics Teachers' formal response to the Next Generation Science Standards. His physics research has focused on atomic and molecular physics tests of fundamental symmetries, nonlinear dynamics and chaos, and computational modeling of gene regulatory networks. He is the author of *Chaos and Nonlinear Dynamics* (Oxford University Press, 2nd Edition, 2000).

Joe Kim is an Associate Professor in Psychology, Neuroscience and Behaviour at McMaster University and is actively involved in the scholarship of teaching and learning. He co-ordinates the innovative McMaster Introductory Psychology program which combines traditional lectures with interactive on-line resources and small group tutorials. The program has been prominently featured in Maclean's, Globe and Mail, Toronto Star and numerous education media outlets. He directs the Applied Cognition in Education Lab (acelab.mcmaster.ca) which aims to understand how cognitive principles such as attention, memory and learning can be applied to develop evidence-based interventions in education and training. The lab uses a variety of tools including cognitive and behavioural testing, eye-tracking and EEG. Current research interests include: retrieval practice, interleaving, mind wandering, and exercise-learning interactions. He also organizes the annual McMaster Symposium on Education & Cognition (edcog.mcmaster.ca) which brings together cognitive scientists, educators and policy makers to explore how cognitive science can be applied to educational policy and instructional design

Les C. Loschky is an Associate Professor of Psychological Sciences at Kansas State University. He received his Ph.D. in Psychology from the University of Illinois Urbana-Champaign. His work is concerned with visual cognition and scene perception, from both a perceptual and a cognitive viewpoint, and its real world applications. His research emphases are on the relationships between eye movements, attention, and higher-level cognitive processes, with applications in human-computer interaction (HCI), computer-assisted instruction (CAI) in STEM education (e.g., Physics and Mathematics education), and educational applications of better understanding the processes involved in visual narrative perception and comprehension

Elizabeth J. Marsh is a Professor at Duke University and the Associate Chair of the Department of Psychology and Neuroscience. She received her Ph.D. in Cognitive Psychology from Stanford University and did her postdoctoral work at Washington University in St Louis. Her interests include how students acquire, maintain, update, and apply their knowledge, with particular interest in writing-to-learn, learning from non-traditional sources, correcting student misconceptions, and personalized learning. She is an Associate Editor at the *Journal of Experimental Psychology: Learning, Memory, and Cognition* and was the guest editor of a special issue of the APA journal *Translational Issues in Psychological Science* on "How Psychological Science Can Improve Our Classrooms." Marsh's work is supported by the US Department of Education, the National Science Foundation, the James S. McDonnell Foundation, and the Spencer Foundation.

Mark McDaniel is a Professor of Psychological and Brain Sciences (1980 Ph.D., University of Colorado), and the founding Co-Director of the Center for Integrative Research on Cognition, Learning, and Education (CIRCLE) at Washington University in St. Louis. McDaniel is known for his work in the application of cognitive psychological principles to education and for his basic research in memory and learning. Over the past 35 years he has published numerous papers related to education, including topics such as pre-questions, discovery learning, feedback, mental models, analogical learning, and classroom studies on testing effects. McDaniel has developed a number of other research foci in the general area of human learning and memory, including projects investigating the learning processes by which people acquire complex concepts. An important aspect of this work is exploring individual differences in the tendency for learners to focus on abstraction versus learning of examples when attempting to acquire complex concepts. His research has been funded by IES, the Luce Foundation, the McDonnell Foundation, NASA, NSF, NIA, NICHD, NIDCD, and NIMH. To facilitate dissemination of research literatures pertinent to learning and education, with Peter Brown and Roddy Roediger, he co-authored a book published by Harvard University Press entitled *Make it Stick: The Science of Successful Learning* (2014).

José P. Mestre is Professor of Physics and Educational Psychology at the University of Illinois. His research is at the intersection of science education and cognitive science, focusing on the learning of physics. He has made contributions in areas such as the acquisition and use of domain knowledge by experts and novices, transfer of learning, and problem solving. He was among the first to publish scholarly articles on the use of classroom polling technologies (clickers) to promote active learning in large classes, and is a co-developer of *Minds-On Physics*, an activity-based high school physics curriculum that is heavily informed by learning research. Recently he has been applying methodologies common in cognitive science (e.g., eye-tracking, change blindness and flicker paradigms) to study learning and information processing by physics novices and experts. He has served on many national committees and boards for organizations such as the National Research Council, The College Board and ETS, and the American Association of Physics Teachers, and has offered Congressional testimony on *The Science of Learning.* He has published numerous journal articles, and has co-authored or co-edited 18 books. He is a Fellow of the American Physical Society.

Toshi Miyatsu is a doctoral candidate in the Department of Psychological and Brain Sciences at Washington University in St Louis working with Dr. Mark McDaniel. He earned a B.A. in psychology from the University of California, Los Angeles, and worked as a lab manager for Robert and Elizabeth Bjork for two years. Broadly speaking, he is interested in conducting cognitive psychological research that has strong educational implications. His current project includes examining the intersection between retrieval practice and the keyword method in foreign language vocabulary learning, and applying cognitive psychological theories of category learning to optimize category learning instruction in STEM courses (e.g., rock categories taught in geology courses).

Rick Moog is Professor of Chemistry at Franklin & Marshall College and the Executive Director of The POGIL Project. He is the 2016 recipient of the George C. Pimentel Award in Chemical Education from the American Chemical Society and the co-recipient with two colleagues of the 2015 James Flack Norris Award for Outstanding Achievement in the Teaching of Chemistry from the Northeast Section of the American Chemical Society. He has been using a guided inquiry approach to teaching chemistry since 1994, and is the coauthor of POGIL materials for general chemistry and physical chemistry. In addition, he has developed guided inquiry experiments for use in the general chemistry laboratory. Moog has given dozens of presentations, posters, and workshops on POGIL across the country and internationally. He is also coauthor of several journal articles and book chapters concerning POGIL, and the coeditor of the ACogPsy Symposium Series volume: *Process Oriented Guided Inquiry Learning.*

Jason W. Morphew earned a B.S. in Science Education from the University of Nebraska and spent 11 years teaching math and science at middle school, high school, and community college level. He earned a M.A. in Educational Psychology from Wichita State where he focused on the interaction of epistemological beliefs and anxiety and the effect of these constructs on math learning, as well as the development of nature of science beliefs among graduate students. He is currently a doctoral student in Educational Psychology focusing on issues from both STEM education and cognitive science. His research interests involve investigating the role of individual differences (e.g., epistemology, metacognition, and identity) on student performance in STEM courses. Recently he has investigated differences in perception and categorization between experts and novices in Physics. He has published journal articles in Physical Review Special Topics-Physics Education Research, Journal of College Science Teaching, and the Journal of Education and Training Studies among others. He is a member of the American Education Research Association, the National Association for Research in Science Teaching, and the American Association of Physics Teachers.

Laura Novick earned a B.S. in Psychology from The University of Iowa and a Ph.D. in Cognitive Psychology from Stanford University. She is on the faculty at Vanderbilt University in the Department of Psychology and Human Development. She is a Fellow of the Association for Psychological Science and the Psychonomic Society, and she served on the National Research Council consensus committee on Discipline-Based Education Research. She conducts research at the intersection of cognitive science and evolution education. Her research centers around the kinds of difficulties students have in understanding and reasoning from evolutionary trees (particularly cladograms) and the extent to which those difficulties can be explained by general perceptual and cognitive principles. She is also interested in the interactions of folk-biological knowledge (e.g., misconceptions about various taxa), domain-specific knowledge, and cognitive/perceptual principles in explaining students' reasoning. In collaboration with Kefyn

Catley, an evolutionary biologist at Western Carolina University, she has co-authored an instructional booklet and laboratory for teaching tree thinking to undergraduate biology students. Both are available for download from the UCMP Understanding Evolution web site.

Olga Pierrakos is a Program Director in the Division of Undergraduate Education (DUE) in the Directorate of Education and Human Resources (EHR) at the National Science Foundation. Pierrakos is also a Founding Faculty and Associate Professor in the Department of Engineering at James Madison University. In August 2017, she will be transitioning as the Founding Chair of the Department of Engineering at Wake Forest University. She has been collaborating with psychology colleagues for about 10 years in the area of engineering education research in the areas of diversity and inclusion, engineering identity, problem based learning and innovative learning-centered pedagogies, assessment of student learning, engineering design, student motivation, faculty engagement, etc. She also conducts research in cardiovascular fluid mechanics and sustainable energy technologies. She holds a BS and MS in Engineering Mechanics and a PhD in Biomedical Engineering from Virginia Tech.

Katherine Rawson is Professor and Director of Experimental Training in the Department of Psychological Sciences at Kent State University. Her research explores how to optimize learning in educationally relevant domains, with current emphasis on strategies that promote the durability and efficiency of student learning, and the self-regulatory processes that support such learning.

N. Sanjay Rebello is Professor of Physics & Astronomy (75%) and Curriculum & Instruction (25%) at Purdue University. His research lies at the intersection of physics education and cognitive science, particularly in the area of visual cognition. Over the past five years, he has been collaborating with cognitive psychologist, Lester C. Loschky, whose area of expertise is visual attention. Together, they with their research groups have explored and exploited the link between physics learning/problem solving and visual cognition. Their research has shown that visual attention in particular areas of a problem correlates highly with successful problem solving performance. Further, they have demonstrated that visual cues and/or outcome feedback can improve problem solving performance on both training and transfer problems, as well as delayed and far transfer problems. More recently, their research has focused on investigation of multi-modal hints and issues of cognitive load in multimedia learning.

Susan Rundell Singer is Vice President for Academic Affairs and Provost at Rollins College. Previously, she was Division Director for Undergraduate Education at NSF and Laurence McKinley Gould Professor, in the Biology and Cognitive Science Departments at Carleton where she served for 30 years. She pursues a career that integrates science and education with a focus on improving undergraduate education at scale. In addition to a PhD in biology from Rensselaer, she completed a teacher certification program in New York State. A developmental biologist who studies flowering in legumes and also does research on learning in genomics, Susan is a AAAS fellow and received both the American Society of Plant Biology teaching award and Botanical Society of America Charles Bessey teaching award. She directed Carleton's Perlman Center for Learning and Teaching, was an NSF program officer in Biology, and is a co-author of the Vision and Change in Undergraduate Biology report and an introductory biology text. She has served on numerous boards, including the NSF EHR advisory committee, Biological Sciences Curriculum Study Board, and the Botanical Society board of directors; is a member-at-large for the AAAS Education Section; participates in the Minnesota Next Generation Science Standards team; and was a member of the National Academies' Board on Science Education. She has participated in six National Academies studies, including chairing the committees that authored *America's Lab Report, Promising Practices in STEM Undergraduate Education* and *Discipline-based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*.

Linda Slakey is a graduate of Siena Heights College (B.S. in Chemistry), and the University of Michigan (Ph.D. in Biochemistry.) She was appointed to the faculty of the Department of Biochemistry at the University of Massachusetts Amherst in 1973. She was Head of the Department of Biochemistry from 1986 until 1991, and Dean of the College of Natural Sciences and Mathematics (NSM) from 1993 until 2000. From 2000 through 2006, she was Dean of Commonwealth College, the honors college of the University of Massachusetts Amherst. As Dean of NSM and of Commonwealth College she was active in supporting teaching and learning initiatives throughout the University, with particular attention to engaging undergraduate students in research, to faculty development activities that promote the transition from lecturing to more engaged pedagogies, and to the support of research on how students learn. From 2006 through 2011 she was Director of the Division of Undergraduate Education at the National Science Foundation. In that context she came to view the challenge of bringing about good pedagogy as national and cultural in scope, and was also afforded the opportunity to come to know many of the people working on this agenda. At present she has a consulting practice in Washington, DC, with appointments as Senior Advisor at both AAU and AAC&U, focused on bringing about a shift in the culture of undergraduate teaching from one in which lecture is an acceptable norm toward one characterized by personal and institutional expectations of more student-centered teaching practices.

Kurt VanLehn is the Diane and Gary Tooker Chair for Effective Education in Science, Technology, Engineering and Math in the School of Computing, Informatics and Decision Science Engineering at Arizona State University. He received a Ph. D. from MIT in Computer Science, and worked at BBN, Xerox PARC, CMU and the University of Pittsburgh. He founded and co-directed two large NSF research centers (Circle; the Pittsburgh Science of Learning Center). He has published over 125 peer-reviewed publications, is a fellow in the Cognitive Science Society, and is on the editorial boards of *Cognition and Instruction* and the *International Journal of Artificial Intelligence in Education*. Dr. VanLehn's research area is intelligent tutoring systems. Most of his current work seeks new applications of this successful technology. For example, three current projects are: (1) FACT, a tablet-based classroom system for helping teachers both orchestrate individual, group and whole-class activities and more deeply analyze student work during complex math formative assessments; (2) Dragoon, an intelligent tutoring system that imparts skill in constructing models of dynamic systems so rapidly that it can be used in science classes to help students understand the systems more deeply; and (3) OPE, an intelligent tutoring system for organic chemistry aimed at keeping students motivated and improving their self-regulated learning skills.

Robin Wright Robin Wright earned a bachelor of science degree from the University of Georgia and a Ph.D. from Carnegie-Mellon University. After postdoctoral training at UC, Berkeley, she was on the faculty of the University of Washington (Zoology Department) before moving to Minnesota in 2003, where she served as Associate Dean for Faculty and Academic Affairs. She currently serves as the Head of the Department of Biology Teaching and Learning, and professor of Genetics, Cell Biology, and Development. Prior to focusing exclusively on undergraduate education, her lab used genetic, cell biological, ecological, and evolutionary approaches to explore cold adaptation. In addition, her laboratory was well known as a great place for undergraduates to pursue research. Over the past 26 years, she has mentored nearly 100 undergraduate researchers. At Minnesota, she helped to develop and co-teaches the Nature of Life orientation program and has been a leader in development of Foundations of Biology, an innovative, team-based introductory biology course for biological sciences majors. She leads HHMI- and NSF-supported initiatives to deliver discovery-based research experience for the thousands of majors and non-majors who take biology classes in the College of Biological Sciences. Prof. Wright has served on the Education Committee of the American Society for Cell Biology and as chair of the Education Committee for the Genetics Society of America. In addition, she was a senior editor of the Journal, Life Science Education and is the founding Editor-in-Chief of a new biology curriculum journal called *CourseSource*. She is a member of the Executive Committee for the HHMI/National Academies of Science-sponsored Summer Institute on Biology Education and the National Academies Scientific Teaching Alliance. She has been named as a National Academies Biology Education Mentor for the past 14 years. She was elected as a fellow of the American Association for the Advancement of Science in 2012 and was recognized by the Genetics Society of America with the Elizabeth Jones Award for Excellence in Undergraduate Education.