Neuroscience & education: A bridge astray?

Michael R. Dougherty

&

Alison M. Robey

Contact information

Michael Dougherty
Department of Psychology
University of Maryland
College Park, MD 20742
mdougher@umd.edu

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Abstract

It is common to encounter the belief that neuroscience holds promise for advancing educational practice – a belief that is predicated on the assumption that neuroscientific findings can be scaled up to inform our understanding of behavior in complex educational settings. In this article, we argue that this belief is not just far fetched, but misdirected. Although we acknowledge the value of neuroscience for understanding brain mechanisms, we argue that it is largely unnecessary for the development of effective learning interventions. We demonstrate how neuroscience findings have failed to generalize to classroom contexts by highlighting the recent popularity and failed results from brain training research. We end by providing two recommendations for how future researchers and policy makers should address neuroscience and its potential for education applications.

It is common to encounter the belief that advances in technologies that allow us to measure activity in the brain will lead directly to interventions that improve learning. Implied by this belief is idea that education stands to benefit from the explosion of research and data generated within neuroscience. These ideas are further propelled by large-scale initiatives such as the BRAIN initiative. However, the idea that neuroscience can have a direct impact in the classroom is a bit far fetched. This notion was first pointed out by Bruer (1997) in his paper entitled “Education and the brain: A Bridge too far”, and elaborated upon in subsequent work (e.g., Bruer, 2006). Bruer’s thesis is simple: the brain is far too complex and we know far too little about how it works for this knowledge to be useful for education. What we learn from neuroscience may well be useful for understanding cognitive phenomena, but it is the later not the former that offers promise for educational practices.

In January of 2015, a group of scientists from education, developmental psychology, cognitive psychology and neuroscience convened a workshop at the White House in Washington DC. The overarching goal of the workshop was to revisit the question of if (and how) neuroscience might drive education practice. Has the field of neuroscience matured to the point at which it can serve as the genesis for identifying neuroscience-based education interventions? Strikingly, though there was discussion of the *potential* for neuroscience to inform education practice, not one of the participants was able to identify an intervention that originated from neuroscientific findings. Despite over 2 decades of research and massive investment in the brain sciences from the National Science Foundation, National Institutes for Health, and the European Research Council, Bruer’s original critique still rings true, but why?

According to Bruer (1997; 2006) the gap between neuroscience and education is too large to bridge without intermediate landing spots. These landing spots lie in psychology, and in particular cognitive and social psychology. The challenge for developing successful education interventions isn't in understanding brain mechanisms, it is in understanding the *behaviors* that the brain manifests in complex learning environments. Understanding behavior is necessary and sufficient for guiding the development of education interventions; understanding the brain is not. To illustrate this point, consider the recent popularity of brain-training, variably known as cognitive training or working-memory training. The basic premise underlying brain-training is the idea that neurological processes can be changed through extensive practice on cognitive tasks, a principle often referred to as brain plasticity. In early work (e.g., Merzenich et al., 1996), researchers argued that principles of brain plasticity could be exploited to develop interventions that could address learning deficiencies (e.g., language learning impairments) by targeting specific neurological processes related to the learning deficiency. The concept of brain plasticity dates back long before the modern field of neuroscience to at least William James (1892), who discussed the concept in relation to experience-based change (what James referred to as the formation of a habit). There is little doubt that extensive practice on a particular task leads to neurological change. For example, several studies show that practice on a task such as n-back, a task believed to rely heavily on working memory skills, can lead to changes in white-matter integrity, gray matter density, and BOLD signal activation patterns (e.g., Takeuchi, Taki, & Kawashima, 2010; Olesen, Westerberg, & Klingberg, 2004). However, the real question for education researchers is whether the observed changes in brain structure generalize, leading to improvements in the types of complex learning that takes place in classroom settings. Sadly, in

regard to brain-training, the answer to this question seems to be ‘no’ (Roberts, et al., 2016; Strong, Torgerson, Torgerson, & Hulme, 2011).

Brain training is emblematic of the gulf between basic neuroscience and education, wherein seemingly promising interventions motivated by neuroscience findings simply do not scale up to behavior. Prior researchers (including the first author of this paper) proposed that brain-plasticity training could be effective at improving core educational competencies such as language comprehension and mathematical reasoning (Atkins, Bunting, Bolger, & Dougherty, 2012). The bridge implied by brain-training research is that because the brain can be modified through training, then it should be possible to train the brain in such a way that will directly improve educational outcomes. For example, targeted training of neurological mechanisms underlying working memory (WM) should in theory result in generalization (i.e., transfer) of training to non-trained tasks (i.e., educationally relevant tasks). In as much as WM is an important core competency for educational success (Alloway & Alloway, 2010), improving WM through training *should* ultimately improve student outcomes.

The assumed link between the neuroscience of brain plasticity and education seemed obvious, however, there are a number of problems with the brain-training to education bridge. First and foremost, the available literature now strongly suggests that brain-training does not reliably generalize beyond the trained tasks, and certainly does not carry over to better educational outcomes (Roberts, et al., 2016). Indeed, before postulating that brain training is a viable intervention, it is necessary to first show brain training leads to changes in basic cognitive processes by showing behavioral improvements on untrained measures of WM or intelligence (for similar arguments, see Harrison et al., 2013), an important intermediate ‘bridge’ between the brain and the classroom. Unfortunately, it does not (Dougherty, Hamovitz, & Tidwell, 2016;

Melbey-Lervag, Redick, & Hulme, 2016; Simons et al., 2016). Second, the assumption that targeted training of the neurological structures responsible for WM will lead to improvements in WM ability relies on a form of reverse inference. Although a set of brain regions may be active while completing a WM task, this does not necessarily mean that those activated regions reflect the latent construct of WM. More specifically, changing the activation pattern of regions used during a WM *task*, does not necessarily mean *WM* has been changed – it merely means that the neural-computational system for carrying out the task has adapted in response to the changing environmental demands. Complicating this inference even further is the fact that activation patterns have been shown to both increase (Olesen et al., 2004) and decrease (Clark, Lawlor-Savage & Goghari, 2017) as a result of training, and moreover, findings showing that structural changes in the brain (i.e., cortical thickness) do not always correspond to regions that show activation changes (Haier, Karama, Leyba, & Jung, 2009). Exactly what neural changes from pre to post training mean for education requires a firm understanding of neuroscience and a well-developed conceptual model that firmly links neurological function to behavior. Finally, even if brain-training did generalize, establishing the link between the neuroscience underlying WM training and educational outcomes requires cognitive theory. Cognitive theory, and, in particular, conceptual models of WM, provide the landing spot required for establishing the plausibility of using brain-training to improve educational outcomes. Indeed, understanding the fundamental nature of WM and how it relates to specific educational outcomes (e.g., reading comprehension, mathematics, etc.) is both necessary and sufficient for motivating the use of brain-training methodologies for education. Thus, the gap between neuroscience and education cannot be bridged without the intermediary stepping stone of cognitive theory. But more to the point, neuroscience is not even needed: Whether or not training (or any other intervention) results in

changes in brain activation or structure is irrelevant to the question of whether “brain” training (or any other intervention) can improve educational success. What is relevant is whether training leads to changes in core cognitive processes (e.g., WM or IQ) necessary for educational success, and whether improvements in those abilities generalize to authentic educational settings. The theory of change requires specification at the cognitive level, but not at the neurological level.

Figure 1 provides a schematic of the various proposed bridges between neuroscience and education. The arrows are color coded to indicate the strength of the link between two specific levels. The strength can also be thought of as how much one level is needed in order to understand the level to which is links. As discussed above, we believe that neuroscience by itself, is not relevant for informing educational practice or for the development of education interventions (red arrows). To date, there are few, if any, examples of successful education interventions that can be attributed to advances in neuroscience. Although we do not believe that neuroscience can inform educational practice directly, we do believe that it can be useful for developing a deeper scientific understanding of cognitive and social phenomena (yellow arrows). However, gaining a deeper understanding of the neuroscientific basis of cognitive and social phenomena is not the goal of intervention research. Neuroscience can and should also play a vital role in the development and refinement of formal models of cognition (yellow arrows; see Forstman et al., 2011). Formal models may well be useful for informing education research, though the strength of formal models as they relate to educational interventions lies in their account of cognitive and social behavior (green arrows), not in their ability to accommodate neuroscience data. As suggested by Krakauer et al. (2017), it is reasonable to assert that neuroscience needs behavior more than behavior needs neuroscience, and we believe this assertion applies to behavior in the classroom. One can develop a high-level model of cognition

without considering the neural implementation, but it is difficult to imagine how a neuroscientist might address questions of behavior without having a well-formed conceptual model of the behavioral task.

In contrast to the above skeptical view regarding neuroscience based educational interventions, there is reason for optimism regarding cognitive-psychological-based interventions. There is an abundance of research based on basic cognitive psychological theory that have proven to be effective at improving learning in classroom settings. These interventions include both general learning practices such as active learning (e.g., Freeman et al., 2014), retrieval practice (see Roediger & Butler, 2011 for review), spaced versus massed learning (see Benjamin & Tullis, 2010 for review), and blocked vs. interleaved practice (see Schmidt & Bjork, 1992 for review). These interventions have all been shown to be effective when incorporated into actual classroom settings at a variety of grade levels (Bude, Imbos, van de Wiel, & Berger, 2011; Lyle & Crawford, 2011; Mayfield & Chase, 2002; McDaniel, Agarwal, Huelser, McDermott, & Roediger, 2011; Seabrook, Brown, & Solity, 2005).

In addition to general practices many interventions exist that target specific learning objectives. Siegler and colleagues have developed a number-based board game that improves a variety of math abilities in low-income preschoolers (Ramani, Siegler, & Hatti, 2012; Siegler & Ramani, 2009). Snow and colleagues created a Word Generation, an intervention that improves academic vocabulary in middle school (Snow, Lawrence, & White, 2009; Lawrence, Rolland Branum-Martin, & Snow, 2014). Additionally, the widely used cognitive science based intervention, Tools of the Mind, has been shown to improve a wide range of executive function skills and improve classroom performance (e.g., Barnett, Jung, Yarosz, Thomas, & Hornbeck, 2008; Diamond, Barnett, Thomas, Munro, 2007). These are just a few of the many current

practices and interventions based on behavioral science research from within cognitive and developmental psychology. For the vast majority of these interventions, the neural correlates are unknown. While learning about underlying neural mechanisms may lead to a better understanding of the brain, it is unclear how that knowledge would lead to any improvements in the interventions.

Summary and recommendations

We offer two recommendations based on the literature reviewed above. Our first recommendation concerns the funding climate. There is, in our view, a need to improve funding for basic and translational research in the areas of cognitive and social psychology to synergize evidence-based intervention in educational science. Though basic neuroscience research is foundational to understanding of brain mechanisms, the practical benefit for the development of educational interventions remains quite limited. If one of the goals of federal funding agencies is to improve educational outcomes and student success, then we believe that investment in the cognitive and social psychological sciences is a more worthwhile investment in both the short- and long-term. Given that federal funding for research is shrinking and the pool of resources is limited, we strongly urge the government to not divert funding from the cognitive and social sciences to the neurosciences.

The second recommendation is a *caveat venditor* and pertains the tendency that scientists sometimes have toward hyperbole when discussing the implications of their results.

Neuroscience has found its way into the minds of educators, marketers, and consumers.

Educators (and parents) are inundated with advertisements for neuroscience-based products that promise to improve everything from memory and attention to classroom performance and

marketers have begun using “neuroscience” as a tool for persuasion, as if neuroscience somehow brings legitimacy to an advertisers claims (Vaughan, 2015). Not to diminish the value of neuroscience, but we believe that it is important for scientists to regulate how they communicate the value of basic scientific findings as they relate to practical applications. This recommendation is not specific to neuroscience, though we believe that it is especially important for neuroscientists to exercise caution due to the fact that the public is more likely to believe claims substantiated by neuroscience data (Weisberg, Taylor, & Hopkins, 2015) and the fact that the gulf between neuroscience and application is so large. In an era in which researchers are increasingly asked to write press releases about their research, it is especially important that the public not be misled about the promise of basic research for addressing applied problems.

Though Bruer’s (1997) original critique is now over 2 decades old, his arguments that the gap between neuroscience and education is “a bridge too far” still hold. But further, we believe that attempts to bridge neuroscience and education might well be a bridge astray. To draw an analogy with physics, it’s one thing to find support for a theoretical proposition in the frictionless environment of the lab; it’s quite another thing for the support to hold when friction is applied. Phenomena that are observed in the frictionless environment of the lab become much more complex with increases in the friction of the real world. Our worry is that a focus on neuroscience may well lead us astray in our quest for evidence-based education interventions in a friction-filled world.

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Figure 1. Graphical depiction of various bridges across levels of theorizing.