

Bridges over troubled waters: education and cognitive neuroscience

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Recently there has been growing interest in and debate about the relation between cognitive neuroscience and education. Our goal is to advance the debate beyond both recitation of potentially education-related cognitive neuroscience findings and the claim that a bridge between fields is chimerical. In an attempt to begin a dialogue about mechanisms among students, educators, researchers and practitioner-scientists, we propose that multiple bridges can be built to make connections between education and cognitive neuroscience, including teacher training, researcher training and collaboration. These bridges – concrete mechanisms that can advance the study of mind, brain and education – will benefit both educators and cognitive neuroscientists, who will gain new perspectives for posing and answering crucial questions about the learning brain.

Introduction

Education is quintessentially a cognitive science, yet the field of education has a troubled history as a scientific discipline [1]. Recent changes in US law and evidence for international disparities in educational achievement among nations with comparable economic success [2,3] have once again brought to the forefront discussions about the science of education, which are often accompanied by a focus on instituting research-based practices in schools [4]. Concurrently, there has been a growing interest in the possibility that cognitive neuroscience can provide a bridge to a new science of education and learning [5–9]. However, surprisingly little attention has been paid to either an overarching conceptual framework or the mechanisms by which bridges between education and cognitive neuroscience might be built. Perhaps the most obvious potential connection, direct-to-classroom application of neuroscience findings has proven to be difficult and unsatisfying [10]. Here, we take a different position by discussing other mechanisms by which the classroom and cognitive neuroscience laboratory might be connected. In our opinion it is not currently useful to focus solely on product or content; instead, we suggest more engagement, concerted thinking and discussion about the *mechanisms* that will enable success and sustainable productivity in the emerging field of mind, brain and education (MBE).

Cognitive neuroscience and education: troubled waters

Within the past decade, there has been much excitement and numerous publications concerning connections between the fields of neuroscience and education, accompanied by the promise that evidence from cognitive neuroscience in particular might provide a way to advance the science of education and learning. Indeed, there has been a proliferation of reviews of cognitive neuroscience findings that might link with educational practice [5,6,11,12]. Typically cited are studies that report structural [13,14] and functional [15–17] changes in the human brain in relation to training. For example, learning to juggle is accompanied by plastic changes in grey matter in mid-temporal and intraparietal regions [13] and intensive remediation with an auditory language processing program is accompanied by functional changes in left temporo-parietal cortex and inferior frontal gyrus that correlate with behavioral linguistic improvements [17]. Some recent reports have gone further to investigate whether such effects generalize beyond a specific domain of instruction; for example, whether training in domain-general competencies such as visual attention has transferable effects on domain-specific competencies such as numerical cognition, reading and emotional processing [9]. It is quite clear from this literature that experience (in interaction with genes and chance) shapes the human brain – that the process of education is inextricably linked to neural change. However, it is not so clear how this knowledge informs educational policy or practice or advances a new, integrated science of education, as has been noted by others [18–20]. Given this, rather than just add to the existing content reviews, we wish to extend the discussion about cognitive neuroscience and education to include practical mechanisms likely to support and engender meaningful integration.

Thus, a larger conceptual framework for understanding MBE as a developing field is needed. This development occurs in the historical context of successful efforts to apply findings from cognitive and developmental psychology (among other fields) to the classroom; these findings are not to be ignored or excluded from the field of MBE, but built upon with the additional perspective of neuroscience. Indeed, we believe that MBE should be characterized by multiple methodologies and levels of analysis in multiple contexts, in both teaching and research, and by members who will in the future effortlessly translate among those levels, in essence a multilingual constituency

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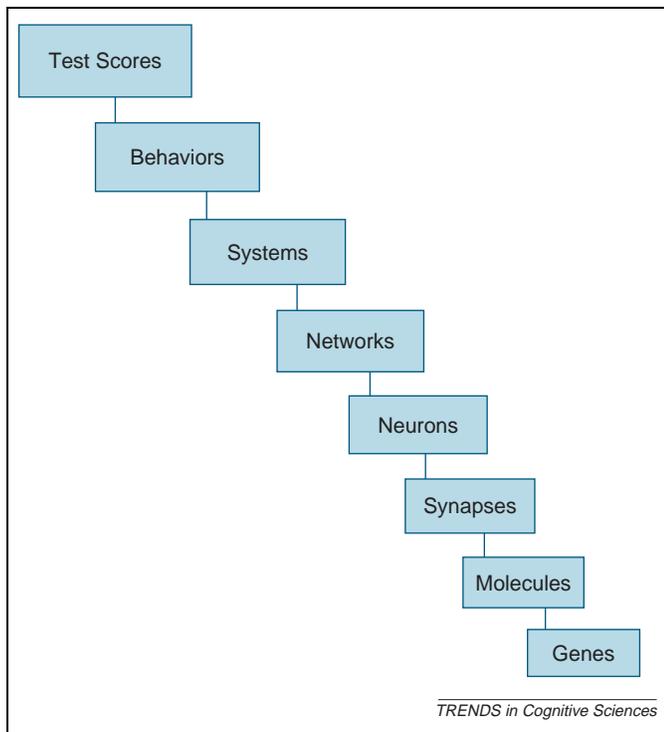


Figure 1. An illustration of the idea of multiple levels of analysis in multiple contexts in both teaching and research in a science of mind, brain, education and learning. Both non-reductionistic translation across levels and each level of analysis itself contribute to an integrated understanding. As a hypothetical example, a student's poor product (test score) might be explicable by inattentive behaviors in the classroom involving attentional systems, particular neural networks and specific neurons in the brain, which can be better understood with additional knowledge about levels of neurotransmitters such as dopamine at crucial synaptic junctions, which can be related both to the classroom environment and to the student's genome. Practitioner-researchers in a science of learning will be multilingual constituents able to integrate and use information across multiple levels of analysis.

(Figure 1). It should also be characterized by a developmental perspective [21] while recognizing that education and brain development [22] are lifelong processes; and by specific mechanisms that address the central crucial question: How do we build the bridges?

Cognitive neuroscience and education: building bridges *Teacher education and training*

One of the potentially most potent mechanisms involves increasing scientific and cognitive neuroscience literacy amongst educators. Although there is a growing body of peer-reviewed literature [6] and websites (e.g. <http://www.teach-the-brain.org>) that provides clear and accurate summaries of progress in the cognitive neuroscience of learning, there are at the same time questionable media reports and numerous other claims about 'brain-based learning' that, in our opinion, often oversimplify, misrepresent, and allow for 'neuromyths' to flourish. On a similar note, although several evidence-based educational interventions exist, it is unfortunate that some programs initially inspired by rigorous research have become commercial applications for which unbiased evaluation is virtually impossible [23,24].

Given evidence from international studies revealing that teacher quality is a significant predictor of children's educational success [3], it is surprising that teacher training does not generally include courses on scientific literacy and the brain and education. We believe that to maximize eventual benefits, it is necessary to take a bottom-up approach to building bridges through initial teacher-training programs that involve cognitive neuroscience, whether through teacher educators trained in the field or cognitive neuroscientists participating in teacher

Box 1. Diversity of approaches: science of learning and education

Historically, the educational research community has struggled to define and conceptualize a science of learning and education [1,48,49]. Although policymakers call for 'scientifically based practice' there is little consensus on the conceptual and methodological bases for such research endeavors. Part of the challenge stems from the need to balance academic freedom with clear standards and principles of research, enabling the generalization and thorough evaluation of educationally relevant research findings while simultaneously maintaining the integrity of each traditional contributing field.

These issues become more complicated when educationally relevant research from different academic disciplines is considered and attempts at integration are made. In the context of bridges between cognitive neuroscience and education it is important to

evaluate the differences and similarities in methodology, approach and conceptualization of scientific research between what one might call 'traditional educational research' and 'traditional cognitive neuroscience research' (see Table I). In so doing, we do not wish to postulate a dichotomy between these approaches but rather to highlight both points of disconnect and connection in an effort to facilitate symbiosis between approaches; there seems no reason that the two approaches cannot work in concert at different levels (see Figure 1 in main text). Only through an awareness and understanding of both the differences and similarities in such research will it become possible to achieve the common ground necessary for an integrative science of mind, brain, education and learning.

Table I. Comparing education and cognitive neuroscience research

	Traditional education research	Traditional cognitive neuroscience research
Goals	Evaluate and improve educational material, methods and pedagogy	Uncover relationships between mind and brain
Methods	Increasing, although not exclusive, emphasis on fully randomized, controlled trials Standardized measures	Noninvasive brain imaging, behavioral and psychophysical measures Experimenter-designed experimental and control tasks
Sample	Increasing pressure to use large sample sizes (100s) ensuring random sampling across a diverse population	Small sample sizes (10–20) owing to constraints of methods and expenses Often little demographic information on samples
Setting	Classroom, school, district, or other education setting High ecological validity Large number of extraneous variables	Highly controlled laboratory setting Low ecological validity Small number of extraneous variables

education. New teacher-training programs in which courses are specifically designed to allow for the investigation and discussion of how to link research and education will foster beginning teachers in appreciating their potentially powerful roles in building bridges in MBE, understanding the developing minds and brains of students, and discovering how conceptualizations of development offered by cognitive neuroscience can inform their own reflections and practice.

Such programs should be characterized by helping future educators to become effective readers and critical evaluators of research findings, encouraging them to ask crucial questions, know how to find answers, make connections across different sources of evidence, and think about how that evidence might affect pedagogy [25,26]. For example, we believe that teaching teachers-in-training about the methods of cognitive neuroscience will help educators to understand the unique constraints of laboratory research (Box 1, Table I). We also expect that training in cognitive neuroscience will not necessarily provide recipes for instruction or radical changes in content knowledge in the subjects teachers-in-training will be teaching. In the same way that medical professionals are trained in molecular biology and organic chemistry, knowledge of which might only indirectly and

often unpredictably influence their later practice, training in cognitive neuroscience will influence teachers' thinking about their practice and students in ways that are indirect and unpredictable *a priori*, but eventually measurable. Although few would challenge the importance of training in cellular biochemistry in medicine, surprisingly few contest the *lack* of training in basic knowledge about the learning brain in education.

In some instances, research in cognitive and developmental psychology tells part of a story, and cognitive neuroscience can reveal more. For example, fMRI research has shown that there are at least two neural systems involved in processing mathematical information [27], which might affect the way that teachers think about approaching mathematics instruction. Similarly, evidence for cortical plasticity associated with intervention, such as reported increases in activation of left occipitotemporal regions selectively accompanying a phonological reading intervention [15], also allow for novel insight. These sorts of findings provide an additional level of analysis to help teachers to evaluate typical dichotomies such as 'procedures versus concepts' [28] in mathematics education or 'phonics versus whole language' [29] in reading instruction from an informed, research-oriented, multifaceted perspective based on empirical evidence.

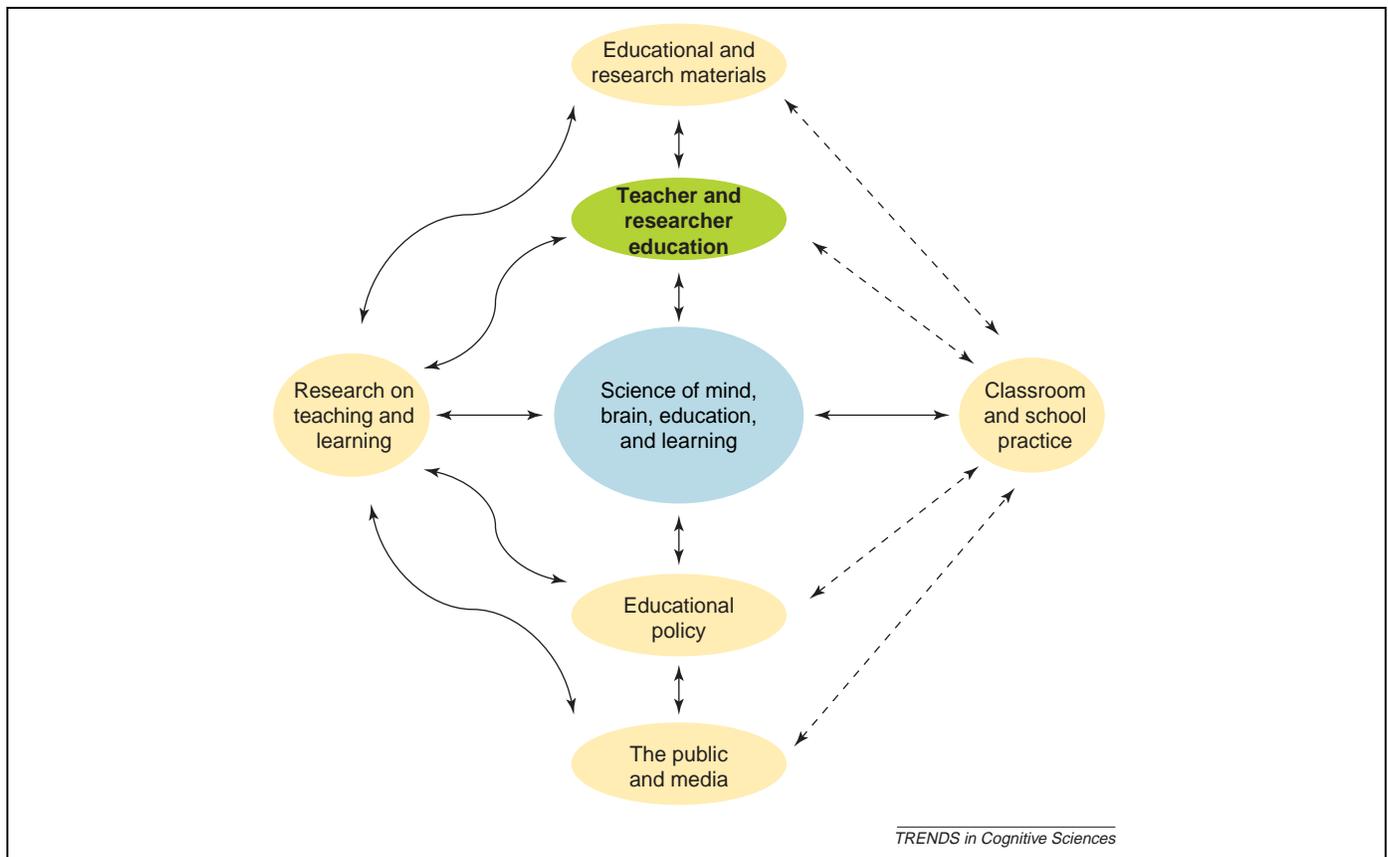


Figure 2. An interdisciplinary science of mind, brain, education and learning will be constructed based on mutual dialogue between researchers of teaching and learning (including but not limited to laboratory, school, classroom and cognitive neuroscience researchers) and educationalists (including but not limited to classroom teachers, aides, specialists and school administrators), amongst other influences. We focus on teacher and researcher education as key to this process of construction; individuals educated within an integrated, multidisciplinary approach will be best suited to build meaningful bridges between the fields of education and cognitive neuroscience. We also focus on research on teaching and learning at different levels and in multiple contexts. Note that all arrows are bidirectional and that some connections are currently more direct (straight, dashed lines) whereas other bridges are less defined (curved, solid lines). Adapted from [47] with permission from the National Academy of Sciences.

Beyond specific academic domains, general knowledge about brain development can be of use to all teachers. For example, recent discoveries about structural and functional changes in the adolescent brain [30] can uniquely inform teachers' understanding of adolescent behaviors. Similarly, knowledge of the prolonged developmental timecourse of neural systems implicated in cognitive control and attention [31] can lead to an appreciation of constraints on learning, from learning to play an instrument [32] to the development of arithmetic skills [33], that cannot solely be attributed to immature knowledge or aptitude. Findings indicating that different aspects of memory are activated in different emotional contexts [34] speak to the links between emotion and cognition. Results of cognitive neuroscience research can also inform an understanding of the roles of sleep [35] and nutrition [36] in brain development and learning and therefore can assist educators deciding if and how to integrate these variables into their curricula. We contend that insights from cognitive neuroscience will confirm, challenge and extend the existing theories that teachers-in-training have about learning and development. We believe that a diversity of perspectives and methods around common questions characterizes the science of mind, brain, education and learning (Figure 2).

It is important to note that the idea of integrating cognitive neuroscience into teacher education is by no means a novel or radical one, but instead a forgotten one. The creation of 'neuroeducators' was proposed over 20 years ago, along with the contention that through the study of brain and behavior the practice of teachers could be transformed and enhanced [37,38]. With the recent availability of noninvasive neuroimaging methods and the advent of cognitive neuroscience, we believe that both technique and literature have now grown enough to support the renewal of a call for interdisciplinary training.

Researcher education and training

Communication between educationalists and scientists needs to be fully bidirectional for the bridges between education and cognitive neuroscience to evenly bear the load of MBE. This not only requires the integration of cognitive neuroscience concepts and methods into teacher training, but also necessitates the training of cognitive neuroscientists in understanding educational process and practice with all of its real-world constraints (Box 1, Table I). Currently, most researchers in developmental cognitive neuroscience – including us – do not have extensive experience working in educational settings, although their research programs often explore issues that arise in such settings. This can lead to misconnections between researchers and educators owing to differences in basic conceptualizations and vocabulary, despite common questions [39].

Thus, whereas traditional education programs need to facilitate broader training in scientific research [25], cognitive neuroscience programs should integrate classroom experience into their curricula. There are a handful of examples illustrating the benefits of scientists in the classroom for students, teachers and researchers [40–42]; bringing educational researchers into cognitive

neuroscientist training programs might also be productive. The benefits for cognitive neuroscientists include the opportunities to train to think in terms of multi-disciplinary bridges beyond the laboratory; to explore novel avenues for funding; and to seek experiences and dialogue with teachers enabling them to see new connections and lines of inquiry related to real-world questions and solutions.

This sort of approach to training blurs the traditional boundary between 'basic' and 'applied' research. Conducting research that addresses questions of fundamental interest in cognitive neuroscience can in some cases be the same as testing hypotheses that are relevant and applicable to educational processes in a science of learning approach. Traditional boundaries between the social and biological sciences also become blurred in MBE; for example, in integrative neuroscientific research on social and ethnic disparities as related to school readiness [43] or the investigation of culture and the brain [44].

Researchers trained to think in terms of bridges will be able to both make new discoveries in the science of learning and test and explain the efficacy of existing educational programs. Although there are several cognitive neuroscience studies evaluating specialized interventions, for example, in language and reading [17] and attention [45], few studies have directly investigated aspects of typical classroom instruction and their effects on students' or teachers' brains. More focused scientific analysis of popular educational approaches will not only lead to a better understanding of 'what works' (e.g. <http://www.whatworks.ed.gov>), but also an understanding of *why* and *how* it does or does not work. In our opinion, an explicit understanding of the mechanisms of successful educational programs across multiple levels of analysis – including the cognitive and neural bases – will provide the foundation for transferable knowledge.

Collaborations between teachers and researchers

We believe that educators empowered with knowledge of the underlying conceptual basis for an intervention [46]

Box 2. Outstanding questions

- Will it be possible to expand the idea of bridges between education and cognitive neuroscience beyond the limited notion of direct-to-classroom application?
- Can the field expand beyond a focus on students to include investigations of teacher learning and changes in teachers' brains?
- Will funding agencies be able to demonstrate adaptability and flexibility in accepting and evaluating nontraditional, interdisciplinary MBE proposals from researchers and practitioners?
- How can the constraints set by institutional infrastructure and funding of existing teacher and researcher training programs be overcome to build the proposed bridges?
- Can educational and scientific policymakers be assisted (and be of assistance) in translating across levels of analysis and in focusing on process rather than product?
- How will future discussions about the methodological and conceptual underpinnings of a science of learning refine and redefine what such a science might look like and how it can best work to serve all relevant constituents?

are likely to be stronger teachers, and researchers empowered with knowledge of real-world questions are likely to design better experiments [47]. Practical ways of starting a dialogue might include focus groups and workshops on specific, mutual interests, classroom and school visits by neuroscientists, or laboratory visits by educators. Any opportunity to establish points of contact and recognize areas of overlap can potentially engender bidirectional dialogue at multiple levels. Such interactions have recently been proposed within a 'design experiment' framework in which educators and researchers establish common ground to create a shared problem representation and develop a mutually beneficial research program [41]. We propose that the challenge of finding meaningful starting points for cross-fertilization within such a framework will be significantly reduced with the creation of the bridges discussed above.

Conclusions

We acknowledge that there are likely to be numerous challenges and obstacles as these (and other) bridges are built and collaborations emerge, including an initial lack of common language and background, a small number of existing points of contact, a lack of a typical forum for interdisciplinary interactions, hostility towards change, and funding issues; there are certainly numerous outstanding questions about the emerging field of MBE (Box 2). But we believe that the long-term outcome for a science of learning and education is too important to delay construction. The first bridge leads to the development of educators who both apply cognitive neuroscience evidence to their practice and generate new, educationally-relevant scientific knowledge through their collaborations with researchers. The second bridge facilitates the development of scientists who can communicate with educators and generate neuroscientific evidence that can be related to education as well as contribute to basic knowledge. Both bridges lead to a multidisciplinary, integrated, collaborative science of mind, brain, education and learning that will lead to measurable benefits for students, teachers and researchers.

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