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COMMENTARY

The Principles and Practices of Educational Neuroscience: Comment on Bowers (2016)

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In his recent critique of Educational Neuroscience, Bowers argues that neuroscience has no role to play in informing education, which he equates with classroom teaching. Neuroscience, he suggests, adds nothing to what we can learn from psychology. In this commentary, we argue that Bowers' assertions misrepresent the nature and aims of the work in this new field. We suggest that, by contrast, psychological and neural levels of explanation complement rather than compete with each other. Bowers' analysis also fails to include a role for educational expertise—a guiding principle of our new field. On this basis, we conclude that his critique is potentially misleading. We set out the well-documented goals of research in Educational Neuroscience, and show how, in collaboration with educators, significant progress has already been achieved, with the prospect of even greater progress in the future.

Keywords: education, educational neuroscience, instruction, neuroscience

> "Education is about enhancing learning, and neuroscience is about understanding the mental processes involved in learning. This common ground suggests a future in which educational practice can be transformed by science, just as medical practice was transformed by science about a century ago." (p. v)
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> Report by the Royal Society, U.K. (2011)

Bowers (2016) has correctly identified that there are a growing number of researchers engaged in work across disciplines that include neuroscience and education. The different names under which this interdisciplinary work proceeds include "Mind, Brain, and Education" and "Neuroeducation," but for the purposes of this paper, we adopt the terminology used by Bowers and refer collectively to these efforts as Educational Neuroscience (EN). Bowers' (2016) contention that the messages from EN are trivial—or trivially wrong—underestimates the scope of research in this new field and the complexity of interdisciplinary research spanning from neuroimaging centers to psychological labs to classrooms.

It is important to stress from the outset that the "neuroscience" in EN refers almost exclusively to cognitive neuroscience. In other words, it is concerned with making links between the neural substrates of mental processes and behaviors, especially those related to learning. Observed correlations between brain imaging data and behavioral change only reflect a small part of this enterprise, with many methodologies shedding light on the mechanisms by which brain function—and in the current context, cognition—is realized. At its core, then, is the established brain-mind-behavior model of explanation that frames cognitive neuroscience (Morton & Frith, 1995), where the behavior is explicitly learning in the

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context of (formal) education. Therefore, although it may be concerned with biological processes and classroom behavior, it also has psychology, quite literally, at the center of its theorizing (Bruer, 1997). It is for this reason we welcome this exchange in the pages of *Psychological Review*.

EN does not favor solely neural levels of explanation, and certainly does not suggest that educational efficacy should be evaluated solely on the basis of neural function. Rather, EN claims that studies of brain function can contribute, alongside behavioral data, to an understanding of underlying learning processes, and that understanding underlying learning processes is relevant to education and can lead to improved teaching and learning. As far as we are aware, there are no established EN research groups who claim that neuroscience, in isolation from psychology or other disciplines, holds any value whatsoever for education. Instead, the exploitation of data from neuroscience is part of a wider perspective on the sphere of causal influences operating on educational outcomes that, for example, now includes a focus on factors such as sleep, diet, stress, and exercise.

Confusions about the scope of EN may stem, in part, from its young age—barely 20 years old, if we date its birth to Bruer's (1997) seminal article. They may also stem, in part, from its small size compared with disciplines such as psychology and more established interdisciplinary fields such as cognitive science—EN comprises a relatively small number of diverse research groups focused on many different educational issues situated in a disparate range of educational contexts. In this article, we attempt to dispel these confusions and others. We first focus on the general relationship between neuroscience, psychology, and education, and we then illustrate this relationship through examples of EN research. We next highlight the importance of engaging with educators on applications of neuroscience and psychological science to education. Importantly, we also correct an unfortunate error in how Bowers (2016) portrays the position of Goswami (2004a). We conclude by defining the current aims and scope of what we understand to be educational neuroscience.

Levels of Explanation

In Bowers (2016), psychology and neuroscience are pitted as competitors in explaining behavior and, using arguments rehearsed by others (Bishop, 2014; Coltheart & McArthur, 2012; Davis, 2004; Schumacher, 2007), it is proposed that psychology should have central status. Bowers states that: "Indeed, unless one is a dualist, the brain necessarily changes whenever learning takes place." However, if one accepts that psychological theory can contribute to educational practice and that neuroscience can contribute to psychological theory, it is illogical to disallow the transitive inference and to instead argue that, in principle, neuroscience is irrelevant to educational practice. Bowers does not set about this challenge directly, but does so by arguing that the study of the brain cannot tell us anything in addition to what we learn from studying behavior. There are a number of problems with this argument.

First, Bowers is uncritical of behavioral evidence. For example, it is not considered that many measures of behavior can often be unreliable and lack validity (e.g., Holloway & Ansari, 2009; Maloney, Risko, Preston, Ansari, & Fugelsang, 2010; Stolz, Besner, & Carr, 2005) or that the absence of a behavioral change on a psychological measure does not imply that no change in behavior has occurred. By arguing that neuroimaging has nothing to add if behavior does not change, Bowers makes a classic misinterpretation of null findings. The point of EN is to use multiple levels of description to better understand how students learn, informed by data at behavioral and biological levels that are associated with such learning. There is no direct route for this process. For example, in understanding the relationship between learning and rewards in the classroom, researchers have drawn on analyses of classroom discourse (how children talk around learning) and behavioral measures such as recall (Howard-Jones, Demetriou, Bogacz, Yoo, & Leonards, 2011), as well as physiological data (e.g., electrodermal activity as a proxy for emotional response: Howard-Jones & Demetriou, 2009) and brain data (Howard-Jones, Jay, Mason, & Jones, 2015). Learning technology and pedagogy informed by findings has involved codesign with teachers (Howard-Jones, Holmes, et al., 2015), with evaluation underway in classroom trials (WellcomeTrust, 2014).

Moreover, the established relation of neuroscience to psychology is one of convergence and constraint, rather than competition. In cognitive neuroscience, for example, signals indicating brain activity or structure can only be meaningfully interpreted by linking them to hypotheses that are derived from behavioral (cognitive) data (Cacioppo, Berntson, & Nusbaum, 2008; Phelps & Thomas, 2003). For this reason, the collection and analysis of behavioral data represents a necessary step in most fMRI experiments (Huettel, Song, & McCarthy, 2008). So, when Bowers claims that instruction investigated by EN is often first motivated by behavioral data, we sincerely hope this is true and continues to be so. In cognitive neuroscience, behavioral and neuroimaging data are considered on a level playing field with each type of data providing information that constrains the insights gleaned from the other, thereby becoming inextricably linked. In other words, there is no knowledge hierarchy, but rather an appreciation that generating multiple sources of data at different levels of description is essential to better understand a phenomenon under investigation (De Smedt et al., 2011). The way the brain develops and operates constrains psychological explanations and explanations of cognitive development relevant to education (Mareschal, Butterworth, & Tolmie, 2013) and behavioral data test and inform the neural investigations, for example by testing the effects of different instruction methods (Delazer et al., 2005). Appreciation of how both biological and behavioral data have contributed to a deeper understanding of mental processes should dispel any sense that brain activity is either trivial when it is correlated with behavior, or irrelevant when not.

Throughout his paper, Bowers states several times that "The most fundamental claim associated with EN is that new insights about the brain can improve classroom teaching." In support of this, a quotation from Blakemore and Frith (2005) is cited which, even in these very early days of EN, carefully avoids a direct "brain scan to lesson plan" claim: We believe that understanding the brain mechanisms that underlie learning and teaching could transform educational strategies and enable us to design educational programs that optimize learning for people of all ages and of all needs (p. 459).

Blakemore and Frith focus first on understanding learning, and only second on how this understanding can then feed into the design of what happens in the classroom. The 'bridge' from neuroscience to educational practice, to use Bruer's (1997) term, is acknowledged by EN researchers to be indirect and complex. The implication that EN is proposing a direct route would be a fundamental misunderstanding of what EN seeks to do. Neuroscience may tell you where to look—that is, what neural functions are typical or impaired and how these operate—but this knowledge must be transformed by pedagogical principles into interventions. These interventions can be evaluated for their effectiveness by behavioral trials in educational contexts, as well as testing any changes in neural markers in laboratory studies, as a means to examine the mechanisms by which any effects have come about.

Bowers' contribution suggests that neuroscience will not help in innovating new and effective teaching methods and that, should it try, these methods should be evaluated by behavioral trials, not by neuroimaging. Although EN is a relatively small and new area for education, six large-scale U.K. trials of educational ideas informed by neuroscience were launched in January 2014 (WellcomeTrust, 2014). Unsurprisingly, these ideas were derived from both neural and behavioral data. In these interventions, educational effectiveness will be judged by behavioral outcomes, not by neuroimaging data. However, the latter still plays an important scientific role. In parallel work, key features of the interventions will be studied under laboratory conditions to evaluate the putative underlying processes which informed them. Interventions informed by both neural and behavioral data can be particularly appropriate for investigations of their efficacy that include neural data, but as a means to further understanding of how this efficacy is coming about—rather than to assess the efficacy itself. In this way, data collected in the classroom and data collected using the methods of cognitive neuroscience can inform one another in a cyclical fashion (McCandliss, 2010). Again, nobody working in the field of EN is advocating dualism or a knowledge hierarchy. Instead, the field embraces multiple levels of explanation that together enhance our understanding of learning and development.

Examples Illustrating the EN Approach and Its Potential

Neuroscience Findings Constrain Psychological Theories

Before the advent of neuroimaging techniques, theoretical models of learning in humans were tethered almost exclusively to behavioral data. The scientific justification for examining the neural substrates associated with a model based on psychological data is that this further constrains the model. Minimally, neuroimaging data can provide construct validity to behavioral observations. One example is provided by Tanaka et al. (2011), who reported evidence at the biological level for the inappropriateness of using the IQ-discrepancy criterion to diagnose dyslexia. They showed that reading difficulties in the presence of intact general intellectual ability do not arise from different causes than reading difficulties accompanied by lower intellectual ability (and consequently, may not require different forms of treatment, although such a hypothesis should be tested empirically with intervention studies). These findings further validated the removal of the IQ-discrepancy criterion in the definition of specific learning difficulties in the latest version of the *DSM-5*.[1] Maximally, in vivo neuroimaging techniques provide an *additional* concrete measurement for testing explanatory models of learning that are derived from behavioral data. Simply put, if a mental process has identified biological substrates, then our theoretical understanding of that process will have greater predictive power if it is constrained by both behavioral data *and* biological data. In our view, this approach has become widely accepted by scientists interested in human behavior. The obvious benefit of a better explanatory model is that it can provide better guidance for interventions—as Kurt Lewin (1951) wrote, "There is nothing so practical as a good theory" (p. 169).

EN Aims to Motivate Educational Thinking and Practice Through Models Arising From Neural and Behavioral Data

Bowers (2016) asserts that neuroscience is irrelevant for "designing and assessing teaching strategies" (p. 2), on the grounds that the sole criterion for judging the effectiveness of instruction is behavioral, that is, whether "the child learns, as reflected in behavior" (p. 10). This is an impoverished view. Imaging studies (with models derived from both behavioral and neural data) have revealed novel decompositions of complex cognitive abilities that were not predictable from behavioral data alone, and these have led to novel instructional studies. For example, electrophysiological research has demonstrated that abnormal processing of letter-speech sound correspondence among dyslexics extends beyond the time suggested by behavioral evidence alone (Froyen, Bonte, van Atteveldt, & Blomert, 2009), and this helped motivate a successful training intervention targeting this ability in 8- to 9-year-olds (Fraga González et al., 2015). However, EN research does not "air drop" neuroscience findings into educational settings and hope for miracles. Rather, it painstakingly builds a *corridor of explanation* from neuroscience findings to psychological constructs to classroom instruction and back (Varma, McCandliss, & Schwartz, 2008). For example, in a series of psychology experiments, Varma and Schwartz (2011) demonstrated that adults mentally represent negative integers as symmetric reflections of positive integers, and that children lack this representation and instead fall back on rules (e.g., "positives are greater than negatives"). This finding was extended in neuroimaging studies revealing that when adults process integers, they recruit brain areas associated with symmetry processing, including left lateral occipital cortex (Blair, Rosenberg-Lee, Tsang, Schwartz, & Menon, 2012; Tsang, Rosenberg-Lee, Blair, Schwartz, & Menon, 2010). With the importance of symmetric integer representations established, Tsang, Blair, Bofferding, and Schwartz (2015) developed novel instructional materials for teaching negative number concepts to elementary schoolchildren. In a classroom study, they demonstrated that these symmetry-based materials resulted in greater learning than conventional number line and cancellation approaches. This nuanced sequence of studies—anchored in neuroscience, mediated by psychology, and applied to education—more accurately represents EN research.

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[1] The *Diagnostic and Statistical Manual* is the standard classification of mental disorders used by mental health providers in the United States, published by the American Psychiatric Association, 5th ed.

The contribution of EN in relation to learning mathematics is also picked out for criticism, especially Butterworth et al. (2011). These authors specifically considered the case of dyscalculia, which they argued is a deficit in number sense, and offered suggestions based on pedagogical theory about how this condition could be remediated. Their argument is supported by a localized abnormality in one neural area (intraparietal cortex) consistently activated during reasoning about number and set size, and part of the large-scale neural network for arithmetic (e.g., Andres, Pelgrims, Michaux, Olivier, & Pesenti, 2011; Menon, 2015; Zago et al., 2001). Therefore an abnormality in understanding sets may be an important criterion for distinguishing dyscalculia from other causes of poor arithmetical development. Butterworth et al. (2011) are clear that "[a]lthough the neuroscience may suggest what should be taught, it does not specify how it should be taught" (p. 1051). Bowers (2016) interprets this statement negatively: "There is no indication how the neuroscience provides any additional insight into how instruction should be designed."[2] However, as that paper also showed, EN researchers can build on this neuroscience finding, combined with psychological and educational findings on the development and training of number representations, to target the concepts learners lack. Specifically, the article cites two examples of interventions based explicitly on learning targets informed by neuroscience—*Graphogame* (Räsänen, Salminen, Wilson, Aunio, & Dehaene, 2009) and *Number Race* (which has been the subject of another successful trial more recently; Sella, Tressoldi, Lucangeli, & Zorzi, 2016). Moreover, Butterworth et al. (2011) take this target, and combine it with an approach "that emulates the manipulative tasks used by SEN teachers" and is based on well-known pedagogical principles of requiring an action to achieve a goal, informative feedback, intrinsic reinforcement, and working adaptively within the 'zone of proximal development'(Vygotsky, 1962). Similar approaches, combining targets defined by EN with pedagogic principles have been deployed in helping children with dyscalculia (Kuhn, Holling, Raddatz, & Dobel, 2014). Again, it is the collaboration of neuroscientists, psychologists, and educators—working across levels of explanation—that characterizes EN research (Howard-Jones, Holmes, et al., 2015).

EN Can Inform Early Identification

Bowers argues that early neuroscience assessments designed to identify children who are at risk for language or mathematics difficulties in the first few years of life are superfluous because interventions cannot begin until children are at school. This argument misrepresents the value of early identification and intervention (i.e., before schooling). Behavioral research has shown that the training of phonological awareness combined with letter knowledge in at-risk children in kindergarten substantially improves reading ability in the first grades of primary school (Schneider, Roth, & Ennemoser, 2000). Neural markers could identify at-risk children even earlier, before they are behaviorally able to take phonological awareness tests (Goswami, 2009). Once these children are identified, they would receive additional instructional support early, from the first day of school, rather than struggling for months before finally failing.

EN Contributes to a Deeper Understanding of Strategies (Including Compensatory Ones)

Bowers suggests that EN targets the remediation of underlying deficits rather than boosting compensating strategies. His position is that "interventions might be best when they are designed to enhance alternative skills (compensatory approach) as opposed to ameliorating the deficits themselves (restitutive approach)." But first we should try to ameliorate the deficit. Individuals with dyscalculia who have no concept of number, and do not understand that numbers have internal relationships, need an intervention that targets their concept of number, not just compensates for not having it. So the more precisely targeted intervention is to enable them to experience how numbers can be constructed from other numbers (Butterworth & Laurillard, 2016). The evaluation then tests whether the behavior improves, with physiological measurement able to detect whether the neural processing takes place.

There is, however, nothing intrinsic about the field of EN that requires it to advocate a restitutive approach in particular. Rather, EN advances a framework that encompasses both approaches to remediation, because both can be justified by a deeper understanding of underlying physiological mechanisms. Regarding compensatory strategies, a long line of studies in the domain of literacy intervention (which is a focus of Bowers' review) has shown that evidence-based remediation programs do not only lead to normalization of neuronal circuits typically involved in reading, but also lead to the engagement of brain circuits typically not associated with reading (Keller & Just, 2009). In this way neuroscience reveals the substrates of compensatory strategies and has the potential to inform ways in which to strengthen them. For example, dyslexic readers engage regions in the right prefrontal cortex more after structured remediation than before (Shaywitz et al., 2004). A better understanding of the function of these brain areas engaged by dyslexic students after intervention may, along with insight from psychology and education, contribute to the design of interventions aimed at furthering strengthening these pathways and enhancing outcomes.

Engagement With Education

EN researchers should be, and usually are, aware that two different types of audience (scientists and educators) are listening to their messages. Although not intended for educators, misinterpretations of data and discussion within specialist science journals found their way into educational thinking before EN began. In fact, awareness of these neuromyths was a significant driver in the creation of the EN field (Bruer, 1997). It is important, therefore, that scientists cautiously consider both the scientific and the educational issues before articulating potential links to practice. If the issues are complex, then the task of understanding and communicating their implications for educators is even more so. It demands scientific expertise but also an understanding of education (Butterworth et al., 2011; De Smedt et al., 2011; De Smedt et al., 2010;

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[2] Moreover, it would be wrong to say we already knew that dyscalculia is attributable to a deficit in understanding sets and their numerosities, as Bowers states in the next sentence: "This is in line with previous suggestions by Gelman and Gallistel (1978) based on behavioral data." Gelman and Gallistel say nothing at all about dyscalculia, nor indeed why some children have difficulty learning arithmetic.

Howard-Jones, 2014). For this reason alone, it is critical to ensure collaboration on EN issues between scientists and educators, and both play integral roles in the EN field.

Bowers criticizes the emphasis the new field places on discussing neuroplasticity. There are, however, good reasons why scientists should emphasize neuroplasticity when articulating messages about education. Educational research suggests a student's theory of learning can be influenced by their ideas about the brain (Dekker & Jolles, 2015), and that this theory of learning is an important determinant of their academic motivation and success (Paunesku et al., 2015). In one highly cited study, adolescents receiving a course that included concepts of neuroplasticity later outperformed peers in terms of self-concept and academic attainment (Blackwell, Trzesniewski, & Dweck, 2007). Other reasons for emphasizing that neuroplasticity extends across the life span include (a) the negative correlation between ideas of biological determinism and teachers' attitudes in the classroom (Howard-Jones, Franey, Mashmoushi, & Liao, 2009; Pei, Howard-Jones, Zhang, Liu, & Jin, 2015), (b) the enduring "Myth of 3," which suggests brain function is fixed at an early age (Bruer, 1999; Howard-Jones, Washbrook, & Meadows, 2012), and (c) the myth that learning problems associated with developmental differences in brain function cannot be remediated by education (Howard-Jones, Jay, et al., 2015). For these reasons, introducing an accurate account of neuroplasticity into the professional development of current teachers and the training of future teachers has the potential to improve how teachers understand student learning (Dubinsky, Roehrig, & Varma, 2013). This is critical because explanatory models can be important to teachers (Anderson & Oliver, 2012). It is questionable whether teachers can integrate ideas into their practice effectively without understanding how and why they work. Put simply, the sharing of such models with teachers is considered by Bowers (2016) as a source of neuromyths, whereas we see it as inoculating against the spread of neuromyths.

Bowers appears to suggest a "just say no approach" to teachers accessing neuroscience except for teachers helping neuroscientists, although we suggest even this one-way communication would be hampered if teachers are prevented from becoming more informed about the brain. Irrespective of the academic debate, teachers are already seeking to understand neuroscience and to think about the relevance of neuroscience findings for improving educational practice (Simmonds, 2014). They are likely to continue doing so. We believe the more constructive path is to improve teachers' access to findings and authentic concepts from the sciences of mind and brain, and for scientists to work collaboratively with educators in creating communications, pedagogy, resources, and assessments that are informed appropriately by these sciences, as well as by educational expertise and knowledge. An approach based on dialogue can help minimize misunderstandings about each other's fields, and so help reduce both the prevalence of neuromyths and the frequency of inappropriate statements aimed at education by scientists (for some examples of these, see Howard-Jones, 2010, pp. 53–57; Payne, 2012). In this context it is important to note that an active approach to combating neuromyths about education is more necessary given that there exists the unwarranted popular belief that data from neuroscience are more convincing, informative, credible, and valid compared with behavioral data (Beck, 2010). Researchers in the EN field are sensitive to this and therefore crucially emphasize that knowledge gained through (cognitive) neuroscience methods should be considered at the same level as data obtained by standard behavioral methods, as we have outlined above.

For these reasons, EN researchers do not generally use phrases such as "brain-based learning" or "brain-friendly learning," contrary to Bowers' claim. A Web of Science search with the phrase "brain-based" reveals the pejorative use of this term in the journal *Mind, Brain, and Education*, which is the longest established journal associated with the field. Bowers has made his arguments on texts that include the remnants of the commercial brain-based industry (e.g., Jensen, 2008; Perez, 2008; Tate, 2005), rather than the academic field of EN which, more than any other, has been sounding the alarm bells and drawing attention to the misunderstandings this industry has helped create (e.g., Geake, 2008; Howard-Jones, 2014; Pasquinelli, 2012). A clear argument for teachers being taught the neuroscience basics is that it supports them in becoming more critical consumers of "brain-based" programs and ideas.

Further, Bowers appears to argue that documenting behavioral improvement is all that matters for education and for teachers, and that understanding of the mechanisms that led to that improvement is unnecessary. Assertions such as "all that matters is whether the child reads better" appear to treat the understanding of underlying processes as irrelevant. This unhelpful view of pedagogy runs counter to decades of research applying the findings of cognitive, developmental, and educational psychology to promote the learning of academic knowledge and skills (Bransford, Brown, & Cocking, 1999; Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013).

To borrow Dehaene's metaphor (Dehaene, 2009), the idea that teachers do not need explanations is like suggesting a washing machine can be fixed without knowing how it works. Because teachers support learning behaviors that are considerably more complex than a broken washing machine, their understanding of the underlying processes is all the more important. Teachers already apply their own notions of how children learn on a daily basis and adapt these to meet the individual needs of learners. In the absence of authentic scientific knowledge, these ideas and practices are sometimes informed by unreliable sources such as the popular media, press and brain-based learning industries. EN researchers believe that teacher understanding and teacher practice can benefit when teacher training and development includes reliable knowledge of what is scientifically known and, perhaps as importantly, what is not known about learning.

Clarifying the Record

As the preceding arguments demonstrate, EN does not claim that neuroscience *alone* will improve education, or that educational achievement should be evaluated using brain imaging techniques. This misunderstanding of the goals of EN is compounded by some unfortunate use of quotes in Bowers (2016). For example, the argument that EN researchers believe that "neuroscience provides a more 'direct' way of measuring the impact of learning than behavior itself" (Bowers, 2016, p. 5) is supported by this apparent quote from Goswami (2004a):

> Although it is frequently assumed that specific experiences have an effect on children, neuroimaging offers ways of investigating this assumption directly . . . For example, on the basis of the cerebellar theory of dyslexia, remedial programs are available that are designed to improve motor function. It is claimed that these programs will also improve reading. Whether this is in fact the case can be measured directly via neuroimaging.

Bowers then writes "But this is getting the things exactly backwards" (p. 6).

Perusal of Goswami's full text makes it clear that she was in fact arguing that neuroimaging can in principle help determine whether specialized remedial programs marketed to educators actually change the neurocognitive systems that they claim to improve, such as those considered to underlie the processes of reading (Goswami, 2004a, 2004b). Bowers substitutes 295 words of Goswami's original text for ellipses, including the sentence immediately preceding the reference to the cerebellar theory of dyslexia: "Our growing understanding of plasticity offers a way of studying the impact of specialized remedial programs on brain function." Indeed, she used the same example in Goswami (2004b):

> Neuroimaging could also be used to measure the impact of training programs devised in response to particular theories of dyslexia (e.g., the DDAT, an exercise-based treatment deriving from the cerebellar hypothesis, which is based on motor exercises such as practice in catching beanbags while standing on a cushion on one leg (see Reynolds, Nicolson, & Hambly, 2003). If an exercise-based package actually improves reading in dyslexic children, there should be measurable effects in the neural systems for reading." (Goswami, 2004b, p. 179)

Goswami has never argued that neuroscience provides a more direct way of measuring the impact on learning than behavior itself. Closer scrutiny of her papers in EN reveals that Goswami argues instead that EN is a long-term enterprise, and that there will be few immediate pay-offs for the classroom teacher (e.g., Goswami, 2012; Goswami & Szucs, 2011).

Conclusions

The Bowers review is a valuable opportunity to reflect on the emerging nature of educational neuroscience. We summarize the key points arising from our reflection here:

- EN is a collaborative attempt to build methodological and theoretical bridges between cognitive neuroscience, cognitive psychology, and educational practice without imposing a knowledge hierarchy.
- All three areas theorize about learning and collect data about learning at their different levels of description, and it is possible for each to inform the other.
- Behavioral and neural data can inform our understanding of learning and so, in turn, choices in educational practice and the design of educational contexts, which can themselves help test and inform the theories from cognitive neuroscience and psychology. EN does not espouse a direct link from neural measurement to classroom practice.
- Educators' ideas about learning, including those which inform practice on a daily basis, may benefit from a more scientific understanding of the processes involved and scientific perspectives and opinion on education should be informed by educational expertise

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