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

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**Abstract**

In his recent critique of Educational Neuroscience, Bowers joins others who have argued that neuroscience has no role to play in influencing education, and that this role should instead fall to psychology. Bowers claims that research in educational neuroscience is misleading, misguided, and cannot meaningfully inform education. In this commentary, we argue that Bowers' assertions reflect confusion regarding the nature and aims of the work in this new field, propagate an inaccurate portrayal of psychological and neural levels of explanation as competing, and exhibit a profound failure to draw on educational expertise – a guiding principle of our new field. On this basis, we conclude that Bowers' critique is misleading and misguided. We set out the well-documented goals of research in Educational Neuroscience, clarifying its relationship to psychology and illustrating its core approaches. We highlight the fundamental importance of engaging with educators regarding applications of neuroscience and psychological science to education.

Keywords: educational neuroscience; education; instruction; neuroscience; mind, brain, and education.

“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)

Report by the Royal Society, UK (2011)

## **Introduction**

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). However, 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 (and especially those related to learning). At its core, then, is the established brain-mind-behavior model of explanation that frames cognitive neuroscience (Morton & Frith, 1995). Therefore, although it may be concerned with biological processes, it also has psychology, quite literally, at the center of its theorizing (Bruer, 1997).

Importantly, Bowers avoids referring to aims or descriptions of work provided by EN researchers, which sets the stage for many of his subsequent confusions. This mistake is understandable, in part. Compared with more established disciplines, such as psychology, and other interdisciplinary fields, such as cognitive science (which includes notably both psychology and neuroscience), EN comprises a relatively small number of diverse research groups focused

on many different educational issues situated in a disparate range of educational contexts. *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.* The claim, or more accurately the aim, of EN is not that neuroscience alone will improve education but that neuroscience should *contribute* to improving education, chiefly through improving our understanding of learning processes, the knowledge of which then can be used to design and evaluate optimal environments of how such learning can be fostered.

We develop these ideas below by first focusing on the general relationship between neuroscience, psychology, and education, and by then illustrating 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. What we do *not* do is directly address the many mistaken arguments in Bowers (2016) because these stem from a fundamental misunderstanding of the goals and findings of EN research. However, his paper includes a number of occasions when quotations of researchers have been used in a misleading way in order to misrepresent EN and we cannot let this stand. Therefore, we have added a discussion of the most prominent examples of this practice in the Appendix.

### **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 be favored. Though Bowers concedes that: “Indeed, unless one is a dualist, the brain necessarily changes whenever learning takes place”, he goes on to argue that the study of the brain cannot tell us anything in addition to what we learn from studying behavior. There are a number of flaws in this argument.

First, Bowers is completely uncritical of behavioral evidence. For example, he does not consider that many measures of behavior are often 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 of behavior does not imply that no change in behavior has occurred. The point of EN is to use multiple levels of description to better understand how students learn, informed by changes at both behavioral and neuronal levels that are associated with such learning. By arguing that neuroimaging has nothing to add if behavior did not change, Bowers exhibits a classic misinterpretation of null findings.

Moreover, the 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 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

(Delazer et al., 2005). Bowers' failure to appreciate how both biological and behavioral data contribute to a deeper understanding may explain his impression that brain activity is either trivial when it is correlated with behavior, or irrelevant when not.

Throughout his paper, Bowers states his point several times that “The most fundamental claim associated with EN is that new insights about the brain can improve classroom teaching”. He cites in support of this a quotation from Blakemore and Frith (2005) which says nothing of the sort:

“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 firstly on understanding learning, and only secondly 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, and Bowers displays a fundamental misunderstanding of what EN seeks to do by implying a direct route has been proposed. The relationship between neuroscience and educational practice can be likened to the relationship between molecular biology and drug discovery, including the arduous process of clinical trials. The basic science tells you where to look, but does not prescribe what to do when you get there. Similarly, 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, and then assessed by behavioral trials in educational contexts, the equivalent of clinical drug trials.



Bowers suggests 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 UK trials of educational ideas informed by neuroscience were launched in January 2014 (WellcomeTrust, 2014). Unsurprisingly, these ideas are derived from both neural and behavioral data, and the success of the ideas will be judged by behavioral outcomes, not by neuroimaging data. 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 will enhance our understanding of learning and development.

### **Examples of EN Research**

This section identifies some of the contributions of EN research through references to examples neglected or misrepresented by Bowers.

### **Neuroscience findings constrain psychological theories**

Before the advent of neuroimaging techniques, theoretical models of learning were tethered almost exclusively to behavioral data. In contrast to Bowers' claims of being misguided, 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. The data further validated the removal of the IQ-discrepancy criterion in the definition of specific learning difficulties in latest version of the

DSM-V<sup>1</sup>. 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). 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 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 through models arising from neural *and* behavioral data**

Bowers 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, i.e. 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, earlier psychological theories proposed that simple arithmetic problems (e.g.,  $2 + 3$ ) are initially solved using counting strategies, but that during learning and development, arithmetic facts come to be

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<sup>1</sup> 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, 5<sup>th</sup> edition.

encoded in long-term memory and accurately retrieved (Ashcraft, 1992; Siegler, 1988). This view has been *corroborated* by neuroscience research findings of separate neural correlates of strategy use versus fact retrieval (Grabner et al., 2009). Note that the differences between such abilities are often difficult to capture with standard behavioral data, such as reaction times of verbal reports (Kirk & Ashcraft, 2001), and that data from cognitive neuroscience can be used to validate empirically, through methodological triangulation, such behavioral data (De Smedt & Grabner, 2015). The developmental shift from strategies to retrieval has been supported by neuroscience findings that individual differences in mathematical achievement are predicted by activation in the left angular gyrus, a neural correlate of fact retrieval (Grabner et al., 2007). This shift has been *recast* by neuroscience findings that, during adolescence, the neural correlates shift towards the left angular gyrus and away from more general memory systems, i.e. the medial temporal lobe and basal ganglia (Rivera, Reiss, Eckert, & Menon, 2005). Moreover, it has been shown that individual differences in the activity in the left angular/supramarginal gyrus during mental arithmetic are predictive of high-school math achievement, thereby providing evidence for the scaffolding role played by arithmetic fact retrieval for higher-level math ability. This relationship was not revealed by the behavioral data alone (Price, Mazzocco, & Ansari, 2013). Finally, this shift has been *applied* to the teaching of new arithmetic operations, for example, leading to the finding that instruction that emphasizes strategies recruits a different cortical network than instruction that emphasizes fact retrieval – and that the former network supports better transfer to novel problems (Delazer et al., 2005).

Bowers criticizes EN for using its models to motivate instruction in a manner that focuses on remediating brain function, rather than behavior. In fact, this is not generally the case since, as

already discussed, these models derive from both behavioral and neural data, and it is difficult to find examples of educational interventions based solely on neural evidence.

The contribution of EN in relation to learning mathematics is picked out by Bowers for criticism, especially Butterworth et al. (2011). These authors specifically cite the case of dyscalculia, which they argue is a deficit in number sense, and offer suggestions based on pedagogical theory about how this condition should be remediated. Their argument is supported by a localized abnormality in the neural region that deals with sets, and is part of the well-known neural network for arithmetic (e.g., (Andres, Pelgrims, Michaux, Olivier, & Pesenti, 2011; Menon, 2015; Zago et al., 2001). Therefore an abnormality in understanding sets is an important criterion for distinguishing dyscalculia from other causes of poor arithmetical development. Butterworth et al. (2011) are clear that the deficit in understanding sets and their properties, including numerosity, should be a target for intervention in the classroom or by digital means, *but they do not specify what this intervention should be*. Indeed, they write, “Although the neuroscience may suggest what should be taught, it does not specify how it should be taught” (p. 1051).

Butterworth et al. explicitly claim only that EN provides a target for such instruction, and that the design of learning contexts for dyscalculia is the province of educators and specialist teachers. Bowers writes ‘There is no indication how the neuroscience provides any additional insight into how instruction should be designed’, whereas Butterworth et al stated that it *does not specify*, but *does provide a target for* how it should be designed. Moreover, it is also misleading to say we already knew that dyscalculia is due to a deficit in understanding sets and their numerosities, as Bowers maintains 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.

**EN interventions draw on multiple levels of explanation**

Bowers claims that neuroscience findings are at too low a level to apply to education, and also contends that this is why EN has not led to novel instructional approaches. He is wrong on both counts. Bowers misrepresents the nature of multidisciplinary research where the component disciplines span levels of explanation. EN research does not “air drop” neuroscience findings into educational settings and hopes for miracles. Rather, it painstakingly builds a *corridor of explanation* from neuroscience findings to psychological constructs to classroom instruction (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 downwards in neuroimaging studies finding 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 Schwarz (2015) developed novel instructional materials for teaching negative number concepts to elementary school children. In a classroom study, they demonstrated that these 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 – represents EN research, and not the caricature offered by Bowers.

**EN informs 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 is simply wrong. The goal is to intervene prior to schooling. Behavioral work 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). EN diagnosis could be even earlier, before children are behaviorally able to take phonological awareness tests (Goswami, 2009). Furthermore, once at-risk children are identified, they would receive additional instructional supports from the first day of school rather than struggling for months before finally failing.

### **EN contributes to a deeper understanding of compensatory strategies**

Bowers also suggests that EN targets the remediation of underlying deficits rather than boosting compensating strategies. This is wrong. Both approaches to remediation 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, we know that 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 help design interventions to further strengthen these pathways and thereby enhance the outcomes of interventions for poor readers.

### **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 published for educators, misinterpretations of data and discussion within specialist science journals found their way into educational thinking before EN began. In fact, these neuromyths were a significant driver in the creation of the EN field (Bruer, 1997). It is important, therefore, that scientists cautiously consider both the science 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 education is 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; Howard-Jones, 2014). For this reason, it is critical to ensure collaboration on EN issues between scientists and educators, as both are integral parts of the EN field. Bowers has misjudged the complexity of issues that EN is attempting to tackle.

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 exists across

the lifespan include (i) the negative correlation between ideas of biological determinism and teachers' attitudes in the classroom (Howard-Jones, Franey, Mashmouhi, & Liao, 2009; Pei, Howard-Jones, Zhang, Liu, & Jin, 2015), (ii) the enduring “Myth of 3”, which suggests brain function is fixed at an early age (Bruer, 1999; Howard-Jones, Washbrook, & Meadows, 2012), and (iii) the myth that learning problems associated with developmental differences in brain function cannot be remediated by education (Howard-Jones et al., 2014). 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).

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 they are supposed to work. Bowers accuses EN of fostering neuromyths through the sharing of such models with teachers, and on this basis cautions against introducing pre-service teachers to neuroscience findings.

However, teachers are already seeking to understand neuroscience and thinking about the relevance of neuroscience findings for improving educational practice (Simmonds, 2014). Rather than a “just say no approach”, the respectful response to teachers' curiosity – and indeed our obligation as scientists – is to report neuroscience findings responsibly to teachers, and to work alongside them in applying these findings to inform better pedagogy and better assessments, and to develop greater vigilance of neuromyths and the overpromises of the commercial educational industry. In this context it is important to note that there exists, indeed, the inappropriate popular belief that data from neuroscience are more convincing, informative, credible and valid compared to 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. Therefore, the research field of EN generally does not, contrary to Bowers claim, use phrases such as “brain-based learning” or “brain-friendly learning.” To be clear, there is no knowledge hierarchy, but an appreciation of multiple sources of data at different levels, with each type of data providing information that constrains the insights gleaned from the other, to better understand how learning takes place and how it can be fostered (e.g. De Smedt et al., 2011).

Further, Bowers appears to suggest that documenting behavioural improvement without understanding the mechanisms that led to that improvement is all that matters for education and for teachers. Assertions such as “all that matters is whether the child reads better” treats 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). It is problematic for several reasons. For example:

1. What does reading better mean? Does it mean pronouncing the words more accurately? Does it mean understanding better what is read? Does it mean being able to read new words as opposed to familiar words? The underlying processes are very different.
2. It surely matters why a child has trouble learning to read. If it is due to a visual problem, then phonological training may not help; if it is due to a phonological problem, then reducing visual stress will not help. The implications are very different.

3. Are the reasons the child is reading better because they are reading more normally, or because they are compensating? Phonological training produces a normalization of cortical activity rather than the recruitment of novel areas. This is precisely the result of the study by Eden et al. (2004) that Bowers dismisses, saying that “neuroscience is irrelevant for assessing the success of any intervention”. On the contrary, understanding how the success was achieved can be educationally very helpful.

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. As 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. As all teachers know, there is no one optimal prescription for all students to learn effectively. Since there are no prescriptive solutions, an understanding of how learning works is essential for a teacher, in order to make decisions about their class teaching and their responses to individual needs. When teacher training does not include a scientific understanding of learning, this understanding and their practice suffers.

A final argument for teachers being taught the neuroscience basics is that it supports them in becoming more critical consumers of “brain-based” programs and ideas.

### **Concluding thoughts**

Educators are increasingly interested in a scientific understanding of learning that includes consideration of both mind and brain. The idea that neuroscience has a role in our understanding of learning and can inform education is evident even amongst researchers whom Bowers identifies as critics. Alferink and Farmer-Dougan (2010), for example, go as far as to state “Yet,

neuroscience research does, indeed, provide important information regarding how children learn and gives some important guidance towards best educational practices” (p. 50). The editors Anderson and Della Salla in the introductory chapter of the text referenced by Bowers complain that, while neuroscience is attractive, it is cognitive science that does all the “heavy lifting” (Della Sala & Anderson, 2012). This may reflect a growing concern that psychology is increasingly being reduced to a sub-branch of neuroscience, fuelled by public interest in the brain (Varma & Schwartz, 2008). Despite this concern, these editors still succeeded in producing a text with 36 other contributors that are mostly positive about greater inclusion into education of an authentic scientific understanding of learning, one that includes neuroscience. In the final few lines of this book, in an imagined conversation with a teacher, Anderson concludes:

“That is my idea of serious triangulation: a theory of the nature of an important cognitive function (e.g. general intelligence) that claims some basis in brain structure or function or whatever; an educational intervention inspired by an attempt to change/develop that particular cognitive mechanism (e.g. some aspect of executive functioning); and an outcome test that is both behavioral (did the intervention lead to changes in the operating characteristic of that mechanism?) and has predicted neural correlates. Then we really would be getting somewhere” (p. 360 – 361).

We would describe this as the EN approach.

The goal of EN is not directly to “improve instruction”. Those of us working in the field talk about something quite different, for example:

“An understanding of how the brain processes underlying number and arithmetic concepts will help focus teaching interventions on critical conceptual activities and will help focus

neuroscience research on tracking the structural and functional changes that follow intervention.” (Butterworth et al., 2011, p. 1053).

“We contend that this field should be conceived as a two-way street with multiple bi-directional and reciprocal interactions between educational research and cognitive neuroscience. On the one hand, cognitive neuroscience might influence research in mathematics education by (a) contributing to our understanding of atypical numerical and mathematical development, (b) paving the way for setting up behavioral experiments and (c) generating findings about learning and instruction that cannot be uncovered by behavioral research alone. On the other hand, educational research affects cognitive neuroscience research by (a) helping to define the variables of interest and (b) investigating the effects of instruction on the neural correlates of learning. This interdisciplinary endeavour will allow for a better understanding of how people learn”. (De Smedt et al., 2010, p. 97).

EN sees its aims as an iterative interaction where each discipline helps the other to progress, not merely a “one-way street linking education to neuroscience” (Bowers, 2016, p. 10).

In summary, EN is concerned with developing models of learning that attend to both neural and behavioral levels of analysis. Researchers in EN are not dualists. EN does not favor neural levels of explanation. It does not suggest that educational efficacy should be evaluated solely on the basis of neural function. EN considers that studies of brain function can contribute, alongside behavioral data, to an understanding of underlying learning processes. EN claims that understanding underlying learning processes are relevant to education and can lead to improved teaching and learning. Bowers’ contention that the messages from EN are trivial underestimates

the scientific and educational complexity of the issues in this new field. Bowers also underestimates the complexity of communicating these issues responsibly to the end-user.

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## Appendix

Bowers (2016) makes extensive use of quotations in his critique of EN. We present two of these here. In many cases, the quotations are taken out of context and, in the first and particularly egregious case, he edits a quotation so that the position expressed is the exact opposite of the actual position of Usha Goswami.

### Goswami (2004)

To support his claim that EN researchers assert that neuroscience provides a more “direct” way of measuring the impact of learning than behavior itself, Bowers writes:

Indeed, sometimes it is claimed that neuroscience provides a more “direct” way of measuring the impact of learning than behavior itself. For example, Goswami (2004) writes:

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 (p. 9).

But this is getting the things exactly backwards.”

In this selective quotation, Bowers reduces nearly 300 words of text to “...”. The resulting partial quote constitutes a clear misrepresentation of Goswami’s scientific position. The entire section of her text in fact reads (with the parts reproduced by Bowers in italics):

*“Although it is frequently assumed that specific experiences have an effect on children, neuroimaging offers ways of investigating this assumption directly.* The obvious

prediction is that specific experiences will have specific effects, increasing neural representations in areas directly relevant to the skills involved. One area of specific experience that is frequent in childhood is musical experience. fMRI studies have shown that skilled pianists (adults) have enlarged cortical representations in auditory cortex, specific to piano tones. Enlargement was correlated with the age at which musicians began to practise, but did not differ between musicians with absolute versus relative pitch (Pantev *et al.*, 1998). Similarly, MEG studies show that skilled violinists have enlarged neural representations for their left fingers, those most important for playing the violin (Elbert *et al.*, 1996). Clearly, different sensory systems are affected by musical expertise depending on the nature of the musical instrument concerned. ERP studies have also shown use-dependent functional reorganization in readers of Braille. Skilled Braille readers are more sensitive to tactile information than controls, and this extends across all fingers, not just the index finger (Roder, Rosler, Hennighausen, & Nacker, 1996). The neural representations of muscles engaged in Braille reading are also enlarged. Finally, it is interesting to note that London taxi drivers who possess ‘The Knowledge’ show enlarged hippocampus formations (Maguire *et al.*, 2000). The hippocampus is a small brain area thought to be involved in spatial representation and navigation. In London taxi drivers, the posterior hippocampi were significantly larger than those of controls who did not drive taxis. Furthermore, hippocampal volume was correlated with the amount of time spent as a taxi driver. Again, localized plasticity is found in the adult brain in response to specific environmental inputs.“

“Plasticity in children, of course, is likely to be even greater. Our growing understanding of plasticity offers a way of studying the impact of specialized remedial programs on

brain function. *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.* If the effects of such remedial programs are specific, then neuroimaging should reveal changes in motor representations but not in phonological and orthographic processing. If the effects generalize to literacy (for example, via improved automaticity), then changes in occipital, temporal and parietal areas should also be observed.”

The elided text results in a complete misrepresentation of Goswami’s argument.

### **Bishop (2007)**

Bowers considers the case of very early diagnosis of risk for dyslexia using neuroscience methods. ‘A number of authors that have suggested the ERPs collected soon after birth (Guttorm, Leppänen, Hämäläinen, Eklund, & Lyytinen, 2010; Guttorm, Leppanen, Poikkeus, Eklund, Lyytinen, & Lyytinen, 2005; Molfese, 2000), or prior to reading instruction ... are anomalous in children who will go on to develop dyslexia, and accordingly, it is claimed that ERPs can be used to diagnose very early’. Bowers goes on to say that ‘Bishop (2007) reviewed a series of ERP studies that claimed to provide evidence that poor auditory temporal processing deficits play a role in dyslexia. She noted a range of problems across the studies, including that they tended to be underpowered, and that the statistical analyses of the studies were unsystematic, with the possibility of false positives given the number of possible differences in a waveform that can be used to predict later reading performance.’



What Bishop actually said about the studies cited here, is that they show ‘promise as a method for comparing clinical and control groups in terms of auditory ERP to equiprobable speech sounds’ (p. 653). Bishop (2007) preceded Guttorm et al (2010), and she does not mention Molfese (2000) at all. Thus to use Bishop’s critique of other studies is very misleading about the studies actually cited.

Clearly, if it turns out to be possible to make an early diagnosis using this neuroscience method, as the evidence currently suggests, then this could be helpful in a way that purely behavioral methods may not be.