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Neuroscience: Viable Applications in Education?

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Abstract

As a relatively young science, neuroscience is still finding its feet in potential collaborations with other disciplines. One such discipline is education, with the field of neuroeducation being on the horizon since the 1960s. However, although its achievements are now growing, the partnership has not been as successful as first hopes suggested it should be. Here the authors discuss the theoretical barriers and potential solutions to this, which have been suggested previously, with particular focus on levels of research in neuroscience and their applicability to education. Moreover, they propose that these theoretical barriers are driven and maintained by practical barriers surrounding common language and research literacy. They propose that by overcoming these practical barriers through appropriate training and shared experience, neuroeducation can reach its full potential.

Keywords

neurosciences, education, research levels, teacher training, neuroeducation

As the field of neuroscience extends to form links with other disciplines, engaging a broader spectrum of society than ever before, neuroscientists must be encouraged to consider the implications and impact of their work for these many different areas. One such discipline, which has received considerable attention over the last 10 years in neuroscience, is education. The idea of neuroscience and education forming an effective partnership, the discipline of neuroeducation, is not particularly new. Indeed the idea was met with much excitement in the 1960s (Gaddes 1968) when it was posited that neuropsychological approaches could be taken to learning disorders. This was followed by a further pulse of enthusiasm with Fuller and Glendening (1985) proposing that so-called neuroeducators should serve both communities to apply knowledge about the brain to the learning process. Nevertheless, some 25 years later, and despite some very significant advances in understanding key neurocognitive processes (Goswami 2006), including those that underlie skills such as reading and mathematics abilities, this partnership has yet to reach its full potential.

Is it then that neuroscience has nothing to offer the field of education? This seems unlikely and indeed Willingham (2009) has suggested that the potential impact that neuroscience may have on education is not even debatable. He cites the example of brain imaging studies providing the deciding evidence in the case of dyslexia being a phonological or visual perception disorder. So why then has this marriage failed to materialize? One obvious suggestion is simply that the two partners in the relationship are unwilling to work closely with each other. However, there is convincing evidence that this is not the case. Indeed, classroom teachers show great enthusiasm for neuroscience as well as a strong desire to learn about the mind and brain (Dommett and others, in press; Pickering and Howard-Jones 2007). Likewise, opportunities for neuroscientists to engage with educators are on the increase and neuroeducation conferences and forums for both parties are becoming more commonplace. That is not to say that neuroscientists are entering into the partnership as enthusiastically as the educators. It is probably fair to say that many are cautious of doing so for fear of seeing their work lost in translation and being overinterpreted and commercialized, in a similar way to that seen when neuroscientists engage in outreach activities (Cameron and Chudler 2003). Given then that there is sufficient drive for this partnership, what other reasons

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are there for the lack of success so far in neuroeducation? We will now consider three theoretical barriers to the marriage, put forward by Willingham (2009), as well as the practical barriers that might explain the current position and suggest how these can be overcome.

Theoretical Barriers to Neuroeducation

First, on a theoretical level, education and neuroscience can be considered fundamentally different in their overall objectives and the manner in which the objectives are pursued (Willingham 2009). Neuroscience is a natural science that investigates the workings of the brain, the functional architecture of the mind, and how the brain and mind map together (Cubelli 2009). In contrast, education, as an artificial science, aims to develop a particular pedagogy that serves a specified goal. Of course, neuroscience might be able to contribute some information to the development of pedagogy, but it is unlikely to be able to assist with all the goals of educational research. Willingham (2009) suggests that at least some of the goals of education often fall beyond the remit of neuroscience, a problem he refers to as the "goal problem."

The goal problem can only be overcome by neuroscientists and educators working together to find common goals upon which they can both agree. Where a common goal cannot be found, we suggest that the two groups should keep a safe distance to protect the integrity of both fields. Even where such a goal does exist, such is the gap between the two disciplines that it is suggested by a number of researchers that the influence of neuroscience on education must be limited to being descriptive rather than prescriptive (Ansari and Coch 2006; Christodoulou and Gaab 2009; Mason 2009) and neuroscientists must be content to remain silent on issues where the differences in levels of analysis prevent any valid contribution (Willingham 2009).

Second, the scale of investigation of the two disciplines also differs significantly (Willingham 2009). Neuroscientists, on the one hand, can conduct investigations at several levels, which vary from examining the role of individual genes and proteins to the study of the whole brain, whereas investigations in education are likely to begin at the level of an individual child. Willingham (2009) refers to this as the "vertical problem." This particular problem deserves further attention, because it seems that all levels of investigation are being applied to investigate constructs relating to education when perhaps only those closest to the level of the whole brain and individual child can have any true relevance in education.

To illustrate this, let us consider research into reading ability that is carried out in neuroscience and what conclusions this may allow for education. Beginning then at the molecular and genetic level, what research is available and what impact can it have on education? Perhaps unsurprisingly, there is less research at this level relating to educational constructs and what is available focuses on reading deficits rather than normal development (Dale and others 1998; Luca and others 2007; Paracchini and others 2008; Stevenson and others 2005; Wadsworth and others 2010). Beyond specific disorders such as attention-deficit hyperactivity disorder (ADHD) and dyslexia, which are only likely to be of great interest to those teaching pupils with those disorders, are some general findings about reading ability. For example, Dale and others (1998) demonstrate that the amount of variance in reading ability that is attributable to genetic influence, as opposed to environmental influences, differs according to ability. That is to say that reading in the poorest readers is more genetically determined than reading in the stronger readers. In addition, Wadsworth and others (2010) showed that when reading difficulties are found in children with high IQs, the level of genetic influences are substantially higher. What does this information mean for educators? Certainly the findings from both studies should encourage educators to recognize that molecular and genetic studies cannot be generalized to a "one size fits all" approach: What is true for one child's reading ability, in terms of heritability, will not necessarily be true for another child. We have found that when teachers are presented with this information they are not surprised that a genetic component exists, but they are often surprised by the fact that the influence of genetics varies with ability. This may be due, in part, to a lack of understanding of the complex role of genes and the environment in behavior, a point relating to the scientific literacy of educators, something we will return to later.

Above the molecular and genetic level, research may also look at the role of particular neurotransmitters and firing of specific subsets of neurons, which we will refer to as the neural activity level. As with research at a molecular and genetic level, the focus of research here is on dysfunction rather than function and reading ability is often considered as part of general cognitive function during the testing of medications for specific disorders, such as bipolar disorder (Pavuluri and others 2006), ADHD (Bonafina and others 2000), and multiple sclerosis (Christodoulou and others 2006), or following substance abuse (Davis and others 1993; Delaney-Black and others 1998). Moreover, this research does not involve actual neuronal recordings or measurements of neurotransmitter release, which is, of course, unsurprising given the invasive nature of such experiments. Therefore, to date, this level has proved somewhat fruitless for applications to education, beyond suggesting that certain medications may or may not improve reading ability in a specific subset of individuals.

The next level of investigation for consideration is that of specific brain regions and circuits, which, due to the invention and widespread use of imaging experiments, has exploded over the last 20 years (Illes and others 2003). We will refer to this level as the functional circuitry level. This is perhaps the first level at which there is a predominance of research from healthy individuals as opposed to those with reading problems or other health problems that deem them part of a clinical population, meaning that results may have greater applicability to the general population for educators. However, the investigation of higher cognition in such studies, although increasing, is still only the focus of a small proportion of studies (Illes and others 2003), meaning that there is still a long way to go in reaching the potential with this level of research in education. From the very early work of Broca and Wernicke, evidence has existed for left hemisphere dominance in language and this has often been understood by educators to mean that the left hemisphere is "for" language. However, there is now significant research suggesting that language performance also correlates with right hemisphere activation (van Ettinger-Veenstra and others 2009). This correlation may depend on the stage of learning with opposing changes to left and right hemisphere activation during learning to read, with the former increasing and the latter decreasing (Turkeltaub and others 2003). Although this is not necessarily of immediate relevance to educators, it does mean that previous ideas in education that children's language ability was dependent solely on their left hemisphere and, by extension, the use of any so-called brain-based interventions, utilizing this idea, does perhaps require rethinking. In addition to examining the lateralization of language, reading ability has been correlated with the microstructure of temporoparietal white matter, which indicates that maturation of this white matter is associated with the development of cognitive functions including reading ability in both healthy adults (Hampson and others 2006) and children (Nagy and others 2004) as well as those displaying impairments (Klingberg and others 2000; Niogi and McCandliss 2006). Again, immediate relevance to education is difficult to see, except to suggest periods of development when reading ability could be optimal.

As well as considering lateralization and myelination, there has been considerable focus on the presence or absence of a visual word area in the left fusiform gyrus, which is particularly responsive to visual words. On the one hand it is argued that this word expertise area could develop through enhanced perception of category members in much the same way as can be seen with other areas of expertise (for example birds or cars; McCandliss and others 2003). Interestingly, these authors suggest that the development of this expertise depends not only on maturation but also on skill. On the other hand, it is argued that this area is activated by tasks that do not require visual representation of the word and that other regions are also activated by visual word representation (Price and Devlin 2003). What then can this research tell educators about reading ability? Perhaps unsurprisingly, there are no significant contributions toward pedagogy for optimizing learning ability. Rather, the research can conclude that several areas of the brain are important in learning to read and reading thereafter and that in some cases this activation changes as reading develops in a manner that is likely to be dependent on both maturation and ability.

In brief, we shall now consider the next level in neuroscience research, which we shall refer to as the syndrome level. This level incorporates research into dysfunction, and for a construct as broad as reading ability this could include all the research into developmental disorders such as dyslexia and ADHD. Considering dyslexia specifically, there is still a wide range of theories as to how dyslexia arises and therefore how it might be best treated (Kronbichler and others 2008; Nicolson and others 2001; Stein 2001). Within education, the theory most heavily subscribed to is often dependent on the local education authority and whose research has been shared with the educators. Indeed, despite the jury being still very much out on how best to treat such children, educators can already be found wedded to particular strategies, suggesting the diversity of theories and findings in the area is not reaching educators.

The final level of neuroscience research is that of observing normal/healthy behavior. This level of research has yielded no useful insights outside of those seen with imaging studies and behavioral genetics that were discussed above. Recall also that this is the level at which education research begins with both individual and group behavior.

Having seen examples of the research for one particular construct relevant to education, it is clear that research at some levels is less useful in education and should therefore avoid entering into a close partnership where any relevance to education may result in the findings becoming too diluted. Many of the situations investigated in neuroscience are vastly simpler than those seen in an education environment, where a wide range of social and environmental factors, not least the educators themselves, can play a role (Mason 2009). Indeed, we suggest that research below the level of functional circuitry is of little immediate and direct relevance in education. Although it may be useful in investigating clinical populations (and treatment) and determining general influences on behavior, it is unlikely to directly lead to pedagogical advances

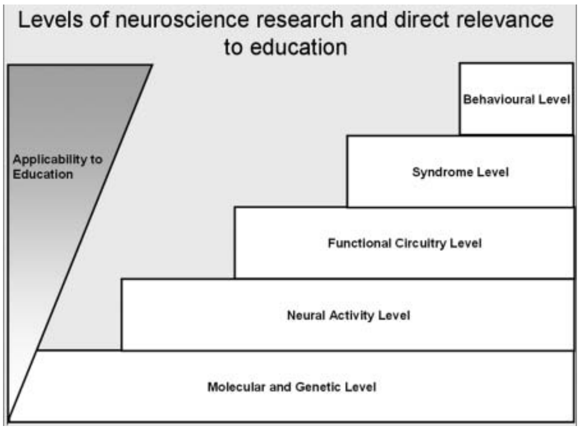

Figure 1. The main levels of research in neuroscience and their direct applicability to education. Below the level of functional circuitry we suggest that there is little direct relevance to education. By contrast, research at or above this level may be relevant, but research questions should be co-constructed by educators and neuroscientists to ensure maximum applicability.

for use with mainstream healthy children. In contrast, work at the circuitry level can be used to develop or test the effects of specific interventions (Simos and others 2007). However, even at this level it is important that neuroscience strives to make experiments as close to the real experience as possible, an issue we will return to later. The gold standard, of course, is to be able to draw conclusions from neuroscientific research with healthy human participants of the appropriate age in a suitable environment. Presently, such research is rare, perhaps because of an emphasis of funding on dysfunction rather than function and the ethical concerns of working with children. However, if neuroscientists can work with educators to devise suitable common goals for research, it is possible that the gold standard will become more achievable and therefore the applicability to education will increase. Figure 1 summarizes the levels of research in neuroscience and their immediate and direct relevance for education. By showing the levels as increasing steps toward the gold standard, both neuroscientists and educators should be aware of making too big a leap in interpretation, where the science may become more speculative than evidence based.

Having carefully considered Willingham's goal and vertical problems, we will now return to his third theoretical problem in combining neuroscience and education—the horizontal problem. Willingham describes this as the problem of translating the content of one field to another. The data of neuroscience are often in the form of electrical, chemical, spatial, and temporal information, but how is this actually applied to education? Willingham and Lloyd (2007) suggest that such data may be useful in assessing educational theories through 1) direct observation of hypothetical constructs in the brain, 2) validation of hypothetical construct with brain imaging, 3) using neural architecture to infer behavioral architecture, and 4) using well-developed knowledge of brain function to select between competing behavioral theories. The key then is that the neuroscience can be used to test or support educational theories rather than derive them.

Practical Barriers to Neuroeducation

Having considered the three theoretical barriers to a neuroscience-education partnership, it is clear that these barriers are, in part, maintained by two practical problems, which, if resolved, could allow the field to flourish. First, and no doubt as a consequence of their differing goals and scales of study, the two parties use a different working language, which makes any direct communication between the two difficult. Indeed, being bilingual was thought to be one of the key characteristics of the original neuroeducator, to be able to converse equally easily with the educators and neuroscientists (Fuller and Glendening 1985). Such is the scale of the problem that communication between the two groups can struggle in both key concepts and experimental design. Concepts such as learning can mean completely different things to educators and neuroscientists, increasing the risk of misunderstanding and overinterpretation of information in translation.

Indeed, a recent study (as yet unpublished) led by Paul Howard-Jones at Bristol University revealed that teachers know very little about the brain, and in some instances, their knowledge was not only poor, but actually incorrect. For example, 20% of new teachers believe that the brain will shrink if five to six glasses of water are not drunk each day. In addition, neuromyths are infiltrating the classroom at an astonishing rate: for example, the notion that children can be labeled as left- or right-brained, with the suggestion that classroom practice be left- or right-brain balanced for each pupil (Goswami 2006). The topic of neuromyths is reviewed extensively elsewhere and therefore will not be covered any further here (e.g., Howard-Jones 2010); rather it is enough for our purposes to acknowledge the role of different working languages in the spread of, or failure to dispel, these myths.

Perhaps more significant than this, as one can always explain key concepts and dispel neuromyths, is the language of experimental design. Concepts such as controls, double blind, and objectivity are commonplace within science research but much less so in education. This means, first, that primary neuroscience research is likely to be, at least in some cases, impossible to understand by educators and, second, that the two groups are likely to find conflict when designing experiments together. Indeed, although action research is now strongly recommended within UK education, much of this research, conducted by classroom teachers, lacks the stringent controls necessary to make any firm conclusions and relies almost entirely on qualitative research methods. This kind of research, of course, has an important role to play, but because it often contrasts with the methods used in laboratory-based research, it can be another point of conflict. We have just finished a large-scale project with classroom teachers and we found them to be highly resistant to the experimental design and control measures that were required. They reported that this was largely because they did not recognize the need for these measures and therefore merely saw them as constraints.

One way in which this problem can be resolved is to give both parties suitable training in the relevant areas. Neuroscientists must be made to be aware of the connotations of the language they use and given training in science communication, something that will stand them in good stead beyond the field of neuroeducation. In addition to the peer-reviewed publications found in neuroscience journals, neuroscientists should consider producing a report in a simpler form containing all key information that is accessible to educators. Such reports can also be beneficial for the neuroscientists, given the extent to which public engagement is now rated by major funding bodies. Indeed, inclusion of these reports or similar information in the form of a blog can be cited in grant applications as evidence of public engagement and therefore directly contribute to the continued funding of the research. Likewise, educators should be given some basic training in neuroscience and research methods, especially if they are to conduct action research. This represents a significant challenge, given the time constraints of the average classroom teacher, levels of funding for such training, and the sheer volume of information that might be deemed basic level.

One successful attempt at such training is currently offered by Flinders University (Australia) in the form of a graduate certificate in neuroscience for teachers to equip them with a basic knowledge of modern neuroscience delivered in a context relevant to their professional practice. Specifically, it aims to provide teachers with an understanding of the principles of modern neuroscience, an ability to critically appraise the neuroscientific literature as it applies to learning, and an ability to apply the principles of neuroscience to understanding classroom practice and behavior.

In addition to this formal training, we have already successfully instigated an effective dialogue with Advanced Skills Teachers (UK teachers with an excellent teaching record and additional training) (Dommett and others, in press) on several neuroscience topics. In this case, the teachers chose the topics that were most relevant to their practice and then had a seminar on the topic from neuroscientists. However, this project required input from around 10 neuroscientists and directly benefited just 30 teachers, a ratio that makes the project uneconomical on a larger scale.

By training teachers in research methods and basic neuroscience they will also be better placed to evaluate so-called brain-based learning products such as Brain Gym, which are often thrust upon them by enthusiastic head teachers or local authorities and for the most part, not supported by neuroscientists (Goswami 2006). A recent article by Sylvan and Christodoulou (2010) provides step-by-step guidance on how a teacher might do this and differentiates between brain-supported, brain-derived, brain-driven, and brain-inspired interventions. This process does require the teacher to be able to evaluate the evidence and methods and therefore relies on background knowledge that can be gained only through training similar to that described above.

Such courses avoid the incorrect beliefs and problems of interpreting neuroscience findings; however, they are offered to existing teachers and, by virtue of funding and motivation, only a subset of these. Coch and Ansari (Ansari and Coch 2006; Coch and Ansari 2009) suggest that teachers should be provided with neuroscience training before they are fully qualified. They postulate that although teachers should not receive the exact same training as neuroscientists, they should be given sufficient training in basic neuroscience concepts and common research techniques for them to critique findings for themselves. Currently in the United Kingdom, much of this initial teacher training is in the form of a one-year postgraduate certification in education, which, having effectively replaced the three-year education bachelor's degree, is an extremely dense qualification. It would therefore be unreasonable to assume that basic neuroscience and research methods training could be incorporated into the existing qualification; however, the inclusion of one or two lectures emphasizing both the need for caution and the potential of neuroscience in education could be considered for inclusion. This could then be followed up through continuing professional development (CPD), perhaps even incorporating distance learning programs, thus avoiding high levels of cost and designated study times, to improve basic neuroscience knowledge and research literacy.

A note of caution should be added here. If, through training and guidance, neuroscientists effectively discredit brain-based learning techniques, the effect on teachers could be extremely negative and set back any long-term joining of neuroscience and education. At present, teachers are encouraged to use such products and many are enthusiastic about them and anecdotally find positive effects on their pupils. If such products are taken away from teachers, they may feel as though they have been stripped of the tools of their trade without any replacements or better options being provided. It is therefore critical that this training does not throw the baby out with the bath water. Teachers must be assured that it is acceptable to use a so-called brain-based technique in the classroom if they find it works for them, even if the scientific evidence for the technique being brain based does not stand up to scrutiny.

The second practical problem is simply finding the time and suitable environment in which these two different professions can work together. Educators, particularly those in the classroom, are notoriously busy, often finding themselves overwhelmed with new educational products and performance targets, reducing the amount of time available to work with neuroscientists, and therefore every effort should be made for such meetings to be within their normal working hours. This is likely to involve significant negotiations with the school ahead of meetings, and both parties should be prepared for such delays in getting started. For their part, neuroscientists may be equally busy and feel quite uncomfortable at having to work in such uncontrolled conditions, in contrast to those in standard laboratory research. However, it is important that neuroscientists not only meet with educators but also see them in their natural environment of the classroom. Likewise, inviting educators into the laboratory to see the research, of all levels, may serve well to break down walls between the two disciplines. Only by shared experiences can the two groups work successfully together.

Table 1. A Summary of the Theoretical and Practical Barriers to Neuroeducation and the Proposed Solutions

Theoretical Barriers	Possible Solutions
Goal Problem	Neuroscience and education must agree common goals and remain separate where this cannot be done.
Vertical Problem	Consideration must be given to the research level and how close this is to the desired gold standard such that leaps between multiple levels are not made. To increase research at the most relevant levels and avoid research focus on dysfunction, neuroscientists and educators should co-construct research projects.
Horizontal Problem	Neuroscience should be used, where possible to distinguish between educational theories rather than drive them.
Practical Barriers	
Language and Scientific Literacy	Neuroscientists should be trained in science communication and encouraged to produce basic reports on peer-reviewed research. Educators should receive basic neuroscience training and training in research methods if they are to engage in action research.
Space and Time	Every effort should be made to work within normal working hours for educators and therefore planning ahead to negotiate with the schools is critical. Both groups should meet with one another in their own territory to share the experience of the work.

Conclusions

We have discussed the theoretical limitations to the marriage between neuroscience and education that were put forward by Willingham (2009) and how solutions to these challenges might be found. In particular, we agree that neuroeducation projects work only on goals and at levels that can have direct relevance to education and that use the neuroscience to support or falsify educational theories rather than derive them. However, we believe this will require a slight change in research mindset from the current focus on dysfunction to function but one that neuroscientists and educators can dictate together. We suggest that underlying these theoretical problems is the practical problem of finding the space and time for communication in a shared language (see Table 1 for a summary of the barriers and solutions). We propose that with suitable training on both sides, these problems can be overcome. Moreover, a commitment to such training and collaboration will allow the field to flourish, such that in another 25 years the neuroeducator role originally put forward by Fuller and Glendening will have reached its potential.

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