

Philosophical Challenges for Researchers at the Interface between Neuroscience and Education

PAUL HOWARD-JONES

This article examines how discussions around the new interdisciplinary research area combining neuroscience and education have brought into sharp relief differences in the philosophies of learning in these two areas. It considers the difficulties faced by those working at the interface between these two areas and, in particular, it focuses on the challenge of avoiding 'non-sense' when attempting to include the brain in educational argument. The paper relates common transgressions in sense-making with dualist and monist notions of the mind-brain relationship. It then extends a brain-mind-behaviour model from cognitive neuroscience to include a greater emphasis on social interaction and construction. This creates a tool for examining the potentially complex interrelationships between the different learning philosophies in this emerging new field.

INTRODUCTION

In the last decade, there has been a growing educational interest in the brain that reflects an increasing belief amongst some scientists, as well as educators, that education can benefit from neuroscientific insights into how we develop and learn. Initiatives have gone by various names, such as 'Brain, Mind and Education', 'Neuroeducation', 'Educational Neuroscience' and 'Brain and Education'. Although these names may come to represent some differentiation in approach, all these initiatives share a common goal: to combine our educational understanding with our biological understanding of brain function and learning.¹ Several reports have assessed the opportunities offered by this new perspective, and a valuable interdisciplinary dialogue is emerging (Byrnes and Fox, 1998; Geake and Cooper, 2003; Goswami, 2004, 2006). In 2000, Uta Frith and her colleague Sarah-Jayne Blakemore completed a commission by the Teaching and Learning Research Programme (TLRP) to review neuroscientific findings that might be of relevance to educators (Blakemore and Frith, 2000). This review attacked a number of 'neuromyths', including those concerning critical

periods for educational development, and highlighted new areas of potential interest to educators such as the role of innate mathematical abilities, visual imagery, implicit processes and sleep in learning. Rather than point out areas where neuroscience could immediately be applied in the classroom, the review sought to highlight neuroscientific research questions that might interest educators, thus making an important initial step towards defining an interdisciplinary area of collaborative research.

In 1999, as the Blakemore and Frith report was being commissioned in the UK, the supranational project on 'Learning Sciences and Brain Research' was being launched by the Centre for Educational Research and Innovation (CERI) at the Organisation for Economic Cooperation and Development (OECD). The first phase of the project (1999–2002) brought together international researchers to review the potential implications of recent research findings in brain research for policy-makers, with a second phase (2002–2006) channelling its activities into three significant areas: Literacy, Numeracy and Lifelong Learning. This OECD project revealed the high level of international interest in developing a dialogue between neuroscience and education, as well as highlighting the diversity of approaches across the world (OECD, 2002, 2007). In April 2005, the TLRP initiated its second initiative in this area, by commissioning the seminar series 'Collaborative Frameworks in Neuroscience and Education'. This produced a commentary, whose popularity (downloading 110,000 copies in the first 6 months after publication) demonstrated the rapidly growing and broadly-based educational interest in the brain (Howard-Jones, 2007). Also in 2007, the specialist journal *Mind, Brain and Education* was launched by Blackwells. In June 2008, a special issue of the educational journal 'Educational Research' was dedicated to neuroscience and education, suggesting that this area is now on its way to becoming an established part of mainstream educational research.

Although interest may be blossoming in this new area, several challenges await those wishing to venture there and some of these are of a fundamental and philosophical nature. Philosophy investigates the 'bounds of sense: that is, the limits of what can coherently be thought and said' (Bennett and Hacker, 2003, p. 399). Those who attempt to work at the interface of neuroscience and education will find themselves straddling at least two, very different, philosophies about learning, each expounding a very different set of concepts. That makes it entirely easy to stray beyond the bounds of sense, at least as interpreted by one or both of these communities. To understand this, and other philosophical challenges faced by researchers within the new field of neuroscience and education, it is first necessary to understand the meaning of 'learning' as it is commonly understood within each community.

1 WHAT IS LEARNING? THE VIEW FROM NEUROSCIENCE

Learning and Memory

In neuroscience, the term 'learning', when used as a noun, is often synonymous with memory. There is now a general acceptance that we

have multiple memory systems that can operate both independently and in parallel with each other. It can be useful to classify these broadly in terms of declarative and nondeclarative systems. The declarative memory system is closest to the everyday meaning of 'memory' and perhaps most clearly related to educational concepts of learning. Defined as our capacity to recall consciously everyday facts and events, this system appears most dependent on structures in the medial temporal lobe (e.g. the hippocampus) and the diencephalon (Squire, 2004). The forming and recalling of declarative memories is known to activate a variety of additional areas in the cortex, whose location can appear influenced by other characteristics of these memories, such as whether these are episodic (the re-experiencing of events) or semantic (facts). Nevertheless, it appears semantic and episodic memory arise from essentially the same system, with models now emerging of how the hippocampus operates in facilitating these different types of declarative memory (Shastri, 2002). Whereas declarative memory is representational and provides us with the means to model the world, and to explicitly compare and contrast remembered material, nondeclarative memory is expressed through performance rather than recollection. Declarative memories can be judged as either true or false, whereas nondeclarative memories appear only as changes in behaviour and cannot be judged in terms of their accuracy. 'Nondeclarative memory' is actually an umbrella term for a range of memory abilities arising from a set of other systems. These include the acquisition of skills and habits (related to changes in activity in the striatum) and conditioned emotional responses (associated with activity in the amygdale). Other nonassociative learning responses (such as when a response is diminished by repetitive exposure to a stimulus) can be linked to reflex pathways located chiefly in the spinal cord.

Connectivity

An appreciation of memory as distributed and involving multiple systems is important, but it tells us little about the process by which a memory is achieved. Within the neuroscience community, there is a common acceptance that human learning, in terms of the formation of memory, occurs by changes in the patterns of connectivity between neurons—or 'synaptic plasticity'. There are two key ways in which this can occur, known as long-term potentiation (LTP) and long-term depression (LTD).

LTP refers to an enduring increase (upwards of an hour) of the efficiency by which a neuron relays electrical information, as a result of a temporal pairing (coincidence in time) between the incoming and outgoing signal. Its role within the hippocampus, an area key to formation of memory, has been the subject of particular focus. LTP refers to the ability of a neuron to adjust its connectivity, in response to signals related in time, an ability celebrated in the expression 'neurons that fire together, wire together'.² This may seem a modest ability but, as can be seen in simulations involving artificial neurons, it affords even small networks the

possibility of organising themselves to produce a type of ‘learning’ with human-like qualities and a range of cognitive functions (Arbib, 2003; McClelland and Rogers, 2003; Hebb, 1947). Such networks can ‘learn’ to identify patterns, make useful guesses and exhibit a graded decrease in functionality when connections are lesioned, as do biological neural networks—so called ‘graceful degradation’. Long-term depression refers to an enduring decrease in synaptic efficiency. This is a mechanism thought to explain, for example, how neurons in the perirhinal cortex decrease their output as a stimulus is repeatedly presented, underlying our ability to recognise familiarity.

It is not presently possible to directly observe the role of synaptic plasticity in human learning, or the mechanisms thought to facilitate it. Instead, less direct evidence is sought. One example of this type of evidence arises from treating animals with a protein-synthesis inhibitor, known to diminish the retention of memory. Animals treated in this way are shown to suffer a slow (over a period of hours) onset of amnesia, which coincides with decreasing ability to maintain LTP. Such studies are typical in their provision of compelling evidence as opposed to a firm proof of the role of LTP. Present data suggests we can be sure such mechanisms are necessary for learning, but we cannot be sure that the plasticity required for learning rests on these alone (Martin *et al.*, 2000). Or, as warned in a recent review, ‘establishing a causal connection between a specific form of synaptic plasticity and the behavioural consequences of specific experiences remains a daunting task’ (Citri and Malenka, 2008, p. 30). Indeed, in recent years, there has been increasing criticism within neuroscience of the synaptic plasticity hypothesis. Doubt has been shed upon whether stable declarative memory formation, lasting over decades, is founded on such an unstable phenomenon as synaptic plasticity. This is one of the considerations underlying suggestions for a genomic hypothesis of memory, in which DNA modifications serve as carriers of elementary memory traces (Arshavsky, 2006; Crick, 1984; Davis and Squire, 1984).

Working Memory

There is another, very important, memory ability essential to the type of learning promoted by education. Working memory refers to our ability to temporarily hold information arriving via our senses, or from a longer term store of memory, in order to process it. It is very limited in its capacity. This is demonstrated when, for example, we are writing down a telephone number. Because we can only hold a few unrelated digits in our working memory, we prefer to receive the number in chunks of just 3–4 digits, writing these down before hearing the next few. Activity associated with working memory has been observed in many different parts of the brain, but particularly in an area of the frontal lobes known as the Dorsolateral Prefrontal Cortex (DLPFC). Rather than being supported by mechanisms of synaptic plasticity and the production of new connectivity, it would appear that the DLPFC supports working memory by controlling

a temporary increase in activity within pre-existing networks that are either within the DLPFC itself or in other areas of the brain where the information is stored (Curtis and D'Esposito, 2003).

Structural Change

In addition to producing changes at the cellular level in terms of connectivity, learning has also been linked to gross structural changes in the brain. Research has shown that learning can produce detectable changes in brain structure over quite short time periods. In a study of adults learning to juggle, the brain areas activated at the beginning of a three-month training period increased in size by the end of it. After three further months of rest, these areas had shrunk back and were closer to their original size (Draganski *et al.*, 2004). It is not presently clear how these structural changes come about and whether, for example, they are due to increased connectivity or the birth of new cells such as glial cells or even neurons.

Functional Correlates

When learning has occurred, it is often possible to observe accompanying changes in biological function. For example, in an fMRI study (Delazer *et al.*, 2003), adults attempting to perform long multiplication generated increased blood flow in the frontal areas associated with working memory load, as these learners worked consciously through new routines step-by-step. However, after practising for a week (25 minutes per day), their performance had improved and imaging showed increased activity in those posterior regions associated with more automatic processing demands. At the same time, frontal activity had decreased in a way indicative of reduced load on working memory. This provides a clear demonstration of how learning is often accompanied by a shift in patterns of activity within brain networks, rather than an increase or decrease *per se* in a single region of the brain. Since we draw on different mental resources when we are first attempting a task, compared with when we are proficient, one may expect a changing relationship between regions of brain activity and learning over time. Thus, any changes in biological activity need to be interpreted in relation to a clear dynamic cognitive model of the learning processes involved and a clear, if often hypothetical, understanding of how different brain networks may be supporting these processes (for discussion see Kaufmann, 2008; Varma and Schwartz, 2008).

2 WHAT IS LEARNING? THE VIEW FROM EDUCATION

Educational ideas about learning are diverse and eclectic in their origins. They are the product of a variety of different processes and forces, including those arising from theoretical educational and psychological

traditions, and other culturally transmitted ideas from within and beyond the teaching profession. The lack of consensus and shifting values within the institutions of education also ensure diversity amongst teachers' individual beliefs. Teachers' personal beliefs develop through an accrued professional understanding and do not usually require empirical validation. A teacher's beliefs may not always be reflected in their practise or their justification for it, and neither of these is immune from pragmatism and the pressures of political expediency.

A recent study in the USA (Snider and Roehl, 2007) supported previous research in revealing a generally atheoretical approach amongst teachers (Pinnegar and Carter, 1990), but with beliefs more consistent with the traditions of constructivism than explicit instruction. At the heart of constructivist theories of learning, is the belief that learners construct knowledge based on their own experiences and prior beliefs. Successful learning requires opportunities for meaningful and authentic exploration, engaging activities, interactive group work and student ownership of the learning process.

The executive of Britain's key programme of educational research (Teaching and Learning Research Programme, TLRP) recently published 'Principles into Practice—a teacher's guide to research evidence on teaching and learning'. A review of this text (TLRP, 2007) provides some further indication of the types of ideas about learning that are currently favoured in the UK. The pull-out centre pages list 10 principles. Principles 1 and 6 expand the concept of what learning can achieve beyond factual recall, emphasising that it must 'equip learners for life in the broadest sense', promoting learners' independence and autonomy such that they have 'the will and confidence to become agents of their own learning'. In their indication of how such learning is achieved, Principles 3, 4, 5 and 7 reflect strong constructivist leanings, recognising 'the importance of prior experience and learning', emphasising the need to assess meaningful understanding and to foster 'both individual and social processes and outcomes'. Indeed, Principle 4 states directly that 'effective teaching and learning requires the teacher to scaffold learning'. 'Scaffolding' is a term well known to educators that describes how a teacher can control elements of a task that are initially beyond the learner's capacity, thus permitting him/her to concentrate attention on those elements that are within his/her range of competence (Wood *et al.*, 1976). Principles 2, 8, 9 and 10 encourage an understanding of learning that extends beyond the school pupil, emphasising the importance of teachers' continuous professional development, the significance of informal learning such as that occurring out of school and policy at institutional and system level. The report from which these principles were drawn likens educational innovations to a pebble being thrown into a pond (TLRP, 2006). The first ripple may be a change in classroom processes and outcomes, but this may have implications for teachers' roles, values, knowledge and beliefs. This may require a change in professional development and training that may, in turn, influence school structure and even national policy. The key point here (illustrated in Figure 1) is that changes at any one of these levels may

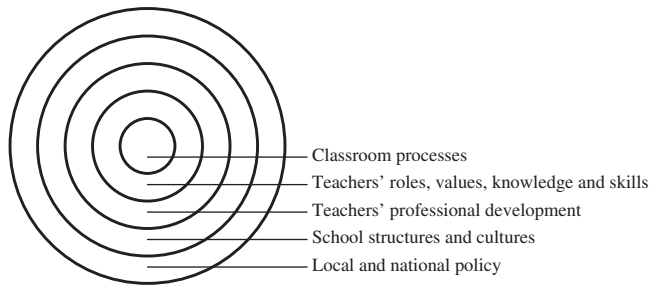


Figure 1 Levels of educational change as proposed in a recent commentary by the Teaching and Learning Research Programme (TLRP, 2006). Adapted from Blakemore and Frith (2000) with permission of the authors.

have implications at another level, and that factors influencing learning are distributed and interrelated with each other in complex ways.

The UK and US reports discussed above make no mention of the biological processes involved with learning. Instead, there is an emphasis on social construction, learning within groups and communities, and the importance of context. Additionally, there are issues of meaning, the will to learn, values and how these and other aspects of learning extend beyond the level of the individual.

3 CONCERNS ABOUT THE INCOMPATIBILITY OF NEUROSCIENTIFIC AND EDUCATIONAL PERSPECTIVES ON LEARNING

Some of the concerns in the new discourse between neuroscience and education revolve around some quite old arguments. One of these is an extreme form of dualism: in which the mind and brain are considered as separate and distinct. The opposite point of view, that they are one and the same, is described here as monism.

Monism: Does Brain = Mind?

Given the very different perspectives on learning within neuroscience and education, it is not surprising that there are concerns about, for example, how helpful neuroscience will be in influencing educational thinking. Some of these concerns have crystallised into objections in principle that have been expressed in terms of basic philosophy. For example, one author has explored the possibility that claims of brain science being relevant to learning involve a 'category mistake' (Davis, 2004). To illustrate this possibility, Davis refers to an article in *Educational Leadership* in which the author discusses learning something new in terms of the brain looking 'for an existing circuit or network into which the information will fit' (Wolfe, 1998, p. 64). In this article, the author goes on to discuss how reading about quantum physics cannot make meaningful sense without

previously stored information about physics. Davis correctly identifies the author's implicit suggestion that she has empirical evidence for a conceptual truth. Further, Davis suggests this is a typical category mistake, in the sense that connections between psychological items are being confused with neurophysiological connections.

In terming this a category error, Davis suggests that the writer considers the mind, or our 'mental domain', as a category distinct from the brain, and that she has made a mistake in using these two categories—a type of dualism gone wrong. An alternative explanation is that the writer is applying a simplistic brain-mind model that appears to inappropriately conflate the two concepts into one—a type of neurocognitive monism. If we consider the mind and brain as the same thing, we can use terms usually associated with the mind to describe the brain, e.g. 'my brain is confused'. In the instance described by Davis, Wolfe may indeed have made an accidental error in her thinking or expression. Alternatively, she may be deliberately conflating mind and brain in order to provide some provisional truth that is more digestible and more clearly supports the pedagogic advice she wants to promote. Suggesting one-to-one correspondences between connections in the mind and synaptic connections in the brain is typical of the type of folk cognitive neuroscience used to market many commercial 'brain-based' educational programmes. But, as is often the case, there is also some grain of truth upon which such explanations are founded. As discussed above, a connection between two concepts in the mind is commonly considered to involve neuronal connections being made, or strengthened, between neurons. As described by Mel (2002): 'pull the average neuroscientist off the street and ask them how learning occurs in the brain, and you're likely to get a reflex response that includes such pat phrases as "activity-dependent changes in synaptic strength, LTP/LTD"'. However, as already described, there are flaws in arguments promoting such mechanisms as a sufficient basis for learning. Therefore, whatever error Wolfe is making, and whether it is deliberate or otherwise, Davis may be correct in suggesting that neuroscience should not presently be used to provide any additional support for promoting concepts of meaning-making that are essentially psychological. Neither might such support be needed, since these psychological concepts are well supported by behavioural studies, even if the neuroscientific search is still on for the biological substrates.

Within neuroscience and psychology, I would argue that scientists are usually quite careful in not conflating mind and brain. I would also argue that neuroscience is well-policed in terms of monism, since there are experts in both the brain and the mind that are defensive of their own territory being misappropriated, as well as peer-reviewed journals where arguments for mind-brain relationships can be thrashed out on the basis of empirical evidence. Others, however, suggest modern neuroscience itself is beset with conceptual confusions arising from attempts to portray our emotional, cognitive and perceptual mental states as states of the brain (Bennett and Hacker, 2003). The claim here is that scientists are prone to their own type of absolute monism, i.e. a belief that the mind can be fully

described by states of the brain. In the sense that our mind's contents is influenced by a variety of other external and internal factors beyond the brain itself, Bennett and Hacker suggest that ascribing our mental states to brain states is no more sensible than ascribing them to an immaterial soul. Bennett and Hacker point out that scientists contribute to the impression that our minds are our brains through unrelenting efforts to use metaphors in describing *representations* in the brain (e.g. 'maps', 'symbols', 'images') when these, as commonly understood, cannot exist there. Pointing out that a map is a pictorial representation that follows conventions and is available to be read by a map-reader, Bennett and Hacker accuse neuroscience of using 'old' terms in new ways. However, the fluid use of such metaphors is often essential in formulating hypotheses that may, in one sense, be false (Churchland, 2005). For example, there are no 2-dimensional maps in the brain that use easily understood conventions. And yet, these metaphors can still be meaningful, such that it is sensible to talk of a complex, interactive but essentially topographical mapping of sensory information at different levels of the sensory pathway. The meaning of map in this context is thus contingent and may develop with the conceptual progress made when such hypotheses are scientifically tested. That said, Bennett and Hacker (2003) correctly point out that the 'original' meanings of such words often stem from a folk psychology that is, itself, not policed by the sorts of revisionary pressures within science. Thus, looking also at the range of examples identified by their analysis, it is easy to understand how the meanings ascribed to the same vocabulary within the neuroscientific and other communities, including education, have been rapidly diverging.

This divergence in meaning, the lack of revisionary pressure and scarcity of forums for interdisciplinary communication (Howard-Jones, in press), makes education vulnerable to monist 'non-sense' and presents the first potential challenge for those working to enrich educational thinking with ideas about the brain. Here, as in the case with Wolfe, implicit monism can be used to provide the impression that conclusive biological evidence exists for a psychological idea about how our minds work, or even that a previous biological observation can now be given psychological relevance, when, in fact, no such evidence exists.

Dualism: Are Brain and Mind Distinct Concepts?

If the mind is entirely separate from the brain, then one can make statements about brain-behaviour relationships without considering the mind, or mind-behaviour relationships without considering the brain. If we consider the mind and brain as separate entities, then the mind has no efficacy upon the brain, or vice versa. Indeed, it is difficult to understand how such a view affords any possibility of mind-brain interaction. Again, like monism, few would express a dualistic view explicitly, but it is not hard to find its implicit reference. Partly, this may be because not explicitly mentioning the potential relevance of biological processes to

complex cognition, particularly of the types associated with problematic areas such as consciousness, can help neuroscientists publish their work without becoming embroiled with issues that psychologists and philosophers feel more comfortable arguing about. For example, consider the quotation from a scientist that Davis uses to defend his position. This suggests that, to a large extent, mind and brain can be considered as two distinct concepts: 'Our brains do not understand. They do not assign or contemplate meanings. They are only electrical and chemical processes in brain activity which would have no meaning except in so far as they are the working of cognitive tools that *people* use to think with' (Harré, 2002).

Such a statement, suggesting that the brain may reflect the mind but does not contribute to mental meaning, brings us close to a dualistic sense of mind as a theoretical concept that should be considered entirely separately from the physical world, including the brain. It is not difficult to find evidence of a dualist approach existing implicitly in matters connected with the brain, including amongst scientists. Degrandpre conducted a scathing analysis (Degrandpre, 1999) of what he called the 'new scientific dualism' by reviewing studies such as that which claimed differences in brain function between two samples of children, with and without a diagnosis of ADHD, might provide the basis for 'biologically valid criteria' for diagnosis (Vaidya *et al.*, 1998). This study implied such biological differences were causal and led to headlines such as 'Test found to identify attention disorder'. As identified by Degrandpre, however, the results might equally be interpreted as the physiological correlates of a behavioural problem caused by some other factor. This extra factor might be an alternative biological issue, or environmental one, such as their education or their home experiences. The tendency to ignore such factors, as in this confusion between correlation and causation, may arise from an assumption, implicit or otherwise, that the brain can be considered independently of the mind and the external influences upon it.

Another example is also helpful in understanding the dangers of such dualism, covert or otherwise, for education. In a local newspaper, a headteacher discusses the challenge provided by a child suffering from ADHD: 'He is uncontrollable and we do not have the facility or resources at the school to cope with his intolerable behaviour ... this is a medical problem and we need to find a solution that is best for everyone' (Parkinson, 2006). Here, it appears that the biological aspects of ADHD have surfaced as its most salient feature just when all educational efforts to support the child have failed. This may be because medicalisation of a problem effectively shifts the focus of professional responsibility. Once separated from the mind, cause can be attributed freely to the biology of the brain and seen as legitimately leaving the educator's domain of influence.

However, brain processes are clearly more than just a *reflection* of our mind's attempt to assign and contemplate meaning, since the suppression of brain processes (through trauma or experimental techniques such as Transcranial Magnetic Stimulation)³ can reduce such mental abilities. Biological processes in the brain thus appear intimately bound up with our

cognitive abilities, even if they cannot be considered as the same thing. Indeed, our personalities, our values and the recall of what we have learnt and experienced can all be influenced by the biology of our brains. Furthermore, and as discussed above, we know that our mental life, as stimulated by our experiences, can influence our brain development at a number of different levels. Thus, whilst dualism can become, for purely pragmatic reasons, an attractive philosophy for educators and scientists alike, it seems unwise and often nonsensical to consider the mind and brain in separation from each other.

Returning to the example of ADHD, the prevalent use of drugs in its treatment does not mean that this disorder is wholly a medical problem beyond the influence of the school environment. On the contrary, there is growing evidence that teachers following informed strategies can play an important role in improving the well-being and academic performance of students suffering from ADHD (Corkum *et al.*, 2005; Gureasko-Moore *et al.*, 2006; Miranda *et al.*, 2002). Recent successful interventions include the application of cognitive and instructional approaches to managing children's behaviour, the inclusion of parents and teachers in such interventions and the training of students themselves in self-management. Such research emphasises the importance of teachers' understanding of the disorder, its medication and management. It also reminds us of the practical benefits of avoiding dualist notions, which can be considered as the second fundamental hazard of a philosophical nature faced by workers at the interface between neuroscience and education.

4 MIND AND BRAIN TOGETHER: COGNITIVE NEUROSCIENCE

Understanding the dangers of monism and dualism leads to a desire to understand mind and brain as concepts under construction, used in describing the mental and biological aspects of our behaviour and intimately related in some, mostly still to be determined, way. The interrelation between mind and brain is not straightforward. Indeed, a whole field of scientific research, cognitive neuroscience, has been founded on efforts to achieve such understanding. Cognitive neuroscientists believe that mind and brain must be explained together (Blakemore and Frith, 2000). In this field, the notion of mind is regarded as a theoretical but essential concept in exploring the relationship between our brain and our behaviour, including our learning.

Seen in this way, the study of cognition appears as a vital bridge in linking our knowledge of the brain to our observations of behaviours involving learning. Indeed, it has been pointed out that without sufficient attendance to suitable cognitive psychological models, neuroscience will have little to offer education (Bruer, 1997).

Figure 2 shows a well known model used by cognitive neuroscientists to combine environmental, biological, cognitive and behavioural levels of description (Morton and Frith, 1995). Invisible cognition is portrayed as sandwiched between behaviour (which is usually observable and

Examples of Environmental factors	Examples of Intra-individual factors	Factor affected
Oxygen Nutrition Toxins	Synaptogenesis Synaptic pruning Neuronal connections	BRAIN
Teaching Cultural institutions Social factors	Learning Memory Emotion	MIND
Temporary restrictions e.g. teaching tools	Performance Errors Improvement	BEHAVIOUR

Figure 2 A model of the brain/mind/behaviour interrelation developed by Morton and Frith (1995) and adapted from Blakemore and Frith (2000) with permission of the authors. The notation in the diagram uses arrows to indicate causal influences. Interactions of external factors with factors that are internal to the individual contribute to causal explanation. 'Facts' are situated at a behavioural and biological level, theories at the cognitive level. The notation can be used to think about links between biology and behaviour via the inferred cognitive level that bridges the gap between them. Adapted from TLRP (2006) with permission of the TLRP.

measurable) and biological processes (which can sometimes be scientifically observed and recorded), with environmental factors influencing outcomes at each level. For example, activity in DLPFC (brain level) can increase with increased working memory load (a cognitive concept), which can occur when an individual carries out a mathematical process (with a behavioural outcome—i.e. producing an answer). In this brain-mind-behaviour model, the term 'environment' must be considered in terms of the level being described. For example, at the brain level, the environment is characterised by biological factors that include oxygen and nutrition. At the level of the mind, the environmental cognitive factors include educational, cultural and social influences whereas behavioural environmental issues include physical opportunities and restrictions.

There are arrows leading from the brain to the mind, and from mind to behaviour. These arrows indicate the directions in which causal connections are most often sought. The issue of cause in cognitive neuroscience, particularly developmental cognitive neuroscience, is very complex and will be returned to again. For the moment, it can be said that behaviour is most often explained in terms of the contents of the mind and cognitive neuroscientists usually attempt to understand the mind by drawing upon our understanding of the brain. However, these arrows might also be drawn as bi-directional. For example, environmental influences (such as being able to access new stimulus) can influence our behaviour that also, in turn, influences our mental processes. If these processes produce learning, this learning can be assumed to have some neural correlate at a biological level, such as the making of new synaptic connections in the brain. As discussed above, continual rehearsal of

mental processes can even produce changes in the brain in terms of its structure, i.e. the shape and size of its component parts. These directions of influence have traditionally been of less interest to cognitive neuroscientists and this may explain their omission in this diagram. However, they are of considerable interest to educators and so have been added here using dotted lines. This is one way in which the most appropriate model of description for neuro-educational researchers may differ from that currently used in cognitive neuroscience.

5 LEAVING BEHIND BIOLOGICALLY PRIVILEGED LEARNING—A ‘LEVELS OF ACTION’ MODEL FOR NEUROSCIENCE AND EDUCATION

Another criticism, in principle, of efforts to include the brain in educational understanding is that neuroscience cannot provide the types of explanation required for improving instruction. Schumacher suggests that, whilst neuroscientific studies may be able to inform psychological understanding about learning, its biologically privileged explanations are of no direct interest to educators. Biologically privileged learning is described by Schumacher as occurring if ‘biological programmes determine which learning processes are initiated by which environmental influences, at which developmental stage, and taking which way of execution’ (Schumacher, 2007, p. 387). In particular, Schumacher (2007) and Davis (2004) emphasise the importance of social and cultural factors in learning that should not be excluded from such explanations. However, there is no conflict here with current neuroscientific thinking. On the contrary, one leading developmental cognitive neuroscientist states clearly ‘Cause is not an easy word. Its popular use would be laughable if it was not so dangerous, informing, as it does, government policy on matters that affect us all. There is no single cause of anything and nothing is determined’ (John Morton quoted in Howard-Jones, 2007, p. 21). Although cause is a problematic construct, it is a helpful tool in trying to alleviate the difficulties faced by many children. However, an important challenge for those reflecting upon cause may be to resist being seduced by explanations exclusively privileging factors of one type, be it biological, psychological or social. This is particularly true for those involved with research at the interface between brain, mind and education. In this sense, then, the model of individual development depicted in Figure 2 may be unhelpful in its emphasis upon the individual.

Given the emphasis upon social processes, the representation of learning in terms of two individuals interacting (as in Figure 3) becomes more suggestive of the complexity that can arise when including consideration of the brain-mind-behaviour relationship within educational contexts. The two individuals may be two learners or, perhaps, a teacher and learner. In this diagram, the space between the individuals is filled by a sea of symbols representing human communication in all its forms. The lines separating brain, mind, behaviour and this sea of symbols are shown as

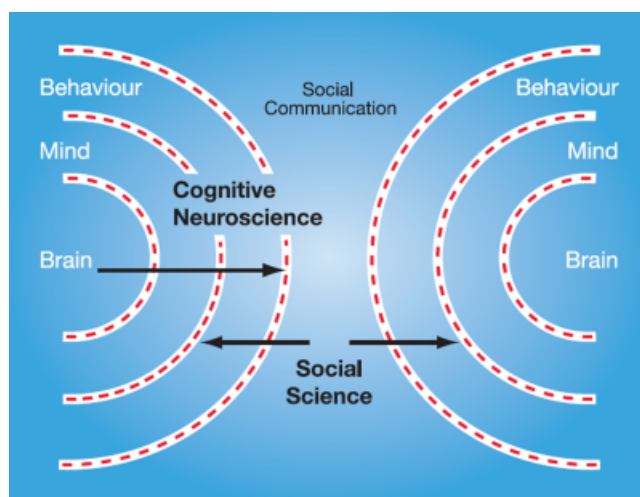


Figure 3 To interrelate the most valuable insights from cognitive neuroscience and the social science perspectives of education (represented by arrows), the brain->mind->behaviour model may need to be socially extended. Even two individuals interacting, as represented here, is suggestive of the complexity that can arise when behaviour becomes socially mediated. Such complexity remains chiefly the realm of social scientists, who often interpret the meaning of such communication in order to understand the underlying behaviour. Cognitive neuroscience has established its importance in understanding behaviour at an individual level but is only just beginning to contemplate the types of complex social domains studied by educational researchers reproduced from Howard-Jones (2007) with permission of the TLRP.

dotted, to emphasise their somewhat indistinct nature and the difficulty in clearly defining concepts lying close to them.

Travelling Across 'Levels of Action'

It is interesting to take an imaginary journey through Figure 3 to gain some further impression of the philosophical challenges face by researchers attempting to integrate neuroscientific and educational thinking, as they struggle to avoid 'non-sense'. Neither natural nor social science, on its own, presently offers sufficient epistemological traction to travel across all levels of description. Let us take the example of a 'neuro-educational' researcher wishing to integrate neuroscientific perspectives on dyslexia with educational understanding and practice. On Figure 3, the arrows attempt to indicate the most frequently (but not exclusively) travelled pathways of investigation associated with these different perspectives. Cognitive neuroscience is marked by an arrow extending from the brain to behaviour. Our neuro-educational researcher might access literature from cognitive neuroscience, including studies of reading acquisition using

neuroimaging. Turkeltaub *et al.* showed there was gradual disengagement of right hemisphere areas (involved with visual memory) and increased activity in left language areas (involved with phonological processing) as children's reading ability increased (Turkeltaub *et al.*, 2003). This is important, since it supports an existing psychological model of reading in which early readers move from a reliance on visual features of letters to developing a phoneme-grapheme correspondence. When biological and cognitive concepts of development resonate in this way, one can feel more confident about the validity of both. These results might also, for example, help explain how trauma in a particular area of the brain influences reading development. It does not, however, provide an entire explanation of how we come to read, since many other factors, including our education, influence this outcome. Neither can it be said that reading begins as a result of activity shifting from right to left areas, since it could as equally be true that the shift occurs because reading has developed. Dyslexic readers show decreased activity in left-hemisphere areas associated with phonological processing. Again, this indicates a potential link between their reading difficulties and their ability to process phonological information, without necessarily proving any causal link (it may, instead, be due to less rehearsal of phonological processing due to some other source of reading difficulty, exacerbating reading problems further). It does, however, help suggest interventions based on improving auditory and oral language skills. Such an intervention, prompted by neuroimaging and behavioural studies, has indeed been shown to help remediate both reading difficulties and the difference in brain activities associated with them (Shaywitz *et al.*, 2004).

Maintaining a careful consideration of the brain-mind relationship allows biological evidence to helpfully augment behavioural evidence and vice-versa, in order to improve outcomes in tractable experimental studies of reading processes and interventions. However, when it comes to a fuller understanding of how such interventions are applied, individual differences in teachers' interactions with children may need to be explored. Here, meaning-based interpretations of the discourse between teacher and pupil are useful in understanding the factors influencing pupils' progress. The meanings ascribed to our actions, including our use of language, are multiple, ambivalent and transitory. The production of language has been a fruitful area for scientific research but the interpretation of meaning within everyday contexts is essentially a problematic area for experimental scientific paradigms. Interpretations of meaning that cannot be judged by the methods of natural science may be considered beyond its jurisdiction (Medawar, 1985). Leaving aside issues of interpretation, the difficulties in using current imaging technology to study everyday social interaction currently provides a barrier for neuroscientists approaching the sea of symbols. The recent flourishing of journals focusing on social cognitive neuroscience demonstrate the beginning of efforts in this area, but interpretation of social complexity remains chiefly the realm of social scientists. Rather than natural science, it is social science, with its own concepts of reliability and validity, that appears most accomplished in

interpreting the meaning of such communications in order to understand their fuller significance (Alexander, 2006).

A researcher wishing to carry out a classroom study of an intervention to remediate dyslexia based on neuroscientific research will, therefore, face the task of integrating insights from both perspectives, and in ways that are mindful of the different epistemologies that gave rise to them. Although challenging, this is very different from a wholesale commitment to a biologically privileged approach to learning divorced from all considerations of context, such as that feared by Davis (2004) and Schumacher (2007). It may be true that ideas about the relationship between learning and development have often emphasised the constraining nature of our biology and our biological development upon our learning. Piaget was criticised for suggesting that learning ‘merely utilizes the achievements of development rather than providing an impetus for modifying its course’ (Vygotsky, 1978, pp. 79–80) and even Bruner, though acknowledging that learning can lead to development, (Bruner, 1974, pp. 417) discussed the psychobiology of pedagogy chiefly in terms of the *constraints* provided by the human nervous system (Bruner, 1972, pp. 118–131). However, in the present model, boundaries with bi-directional permeability emphasise the role of the educational social environment, and to an extent that it influences our biological development. Such a model, compared with notions of biological privilege, also reflects more appropriately the present thinking within developmental cognitive neuroscience.

What About the Free-Will of the Individual?

Educators believe they are striving to produce autonomous learners, personally motivated and able to exercise their own free will when learning. As discussed above, effective teaching and learning is considered by many to depend upon the promotion of learners’ independence and autonomy (TLRP, 2007, p. 9). Some researchers within neuroscience, on the other hand, are presently unsure how, and even whether, free-will comes into existence. Studies of apparent mental causation suggest that unperceived causes of action fail to influence our experience of will, suggesting that conscious will is an illusion. For example, when Transcranial Magnetic Stimulation was applied to influence respondents’ movements of their fingers, they reported that they were consciously willing their fingers, even though this was clearly not the case (Brasil-Neto *et al.*, 1992). In spontaneous intentional finger movement, another study has shown that electrical brain activity precedes action by at least 550 ms, with awareness that they had made the decision *following* some 350–400 ms after this signal (Gazzaniga, 1995). Some scientists suggest, therefore, that our sense of free will is a trick, just the mind’s way of estimating its own *apparent* authorship by drawing causal inferences about relationships between thoughts and actions (Wegner, 2003). Unsurprisingly, this has been identified as another type of biological privilege likely to cause conflict for those working at the interface between neuroscience and

education (Giesinger, 2006). However, educators can feel reassured that denying the existence of free will bring neuroscience into conflict not just with education but also with the entire legal system (Burns and Bechara, 2007). Since discussions about the existence of free-will are very bound up with those about consciousness, they are unlikely to be resolved in the near future (Tancredi, 2007). In the meantime, we most of us share, to a greater or lesser extent, some existing construction about free-will as a highly prized causal factor in our behaviour.

Despite the popularity of educational concepts such as the 'independent learner' and the 'autonomous learner', free will has never been a serious focus of educational research, possibly because of the conceptual and methodological difficulties associated with studying it. This fact, together with the ambivalence of neuroscience towards the concept of free will, suggests there may be a danger that the role of free will can be conveniently overlooked by those researching at the interface between neuroscience and education, despite this being antithetical to present educational aims. To understand how such concepts may be included, it may be useful to consider the field of social psychology, where potential conflicts between perspectives historically exist quite similar to some of those already discussed. In the area of personal growth and development, the role of free will is also highly valued and frequently reflected upon by humanitarian psychologists employing experiential perspectives. One such psychologist is Richard Stevens, who has considered how experiential perspectives embracing issues of free will and autonomy may be considered alongside insights from the natural and social sciences. Stevens' 'Trimodal' theory interrelates perspectives in a practical manner based upon 'mode of action' (Stevens, 1998). Although originally intended to describe social behaviour, the trimodal approach will be illustrated here in terms of learning. In trimodal terminology, the *primary* mode of learning arises from the physical embodiment of the learner. This provides a basis for learning that is best described in terms of biological and neuro-physiological processes whose scientific study can help explain our thinking and learning mechanisms in terms of causal models that may be informed by, and inform, our understanding of brain function. In trimodal theory, it is these primary mechanisms that support the emergence of symbol systems and the use of language, thus facilitating a *secondary* basis for learning. It is the use of symbol systems that makes it a meaning-based mode of learning that involves interpretation by those participating in it and by those attempting to investigate it. Thus, as discussed above in the context of teacher-pupil interaction, Stevens suggests this basis for learning is often best explored through the perspectives of social science, with a perspective that is appropriately sensitised to the unique and complex nature of meaningful social contexts. According to Stevens, it is our ability to use meaningful symbols that crucially supports our formation and manipulation of concepts, including those that describe ourselves. Thus, from the secondary symbolic mode of action emerges a third basis for action—our reflexive awareness. This *tertiary* mode involves self-awareness and reflective choice. Here, our actions are less

determined solely by primary biological and cognitive processes and/or by secondary meaning-based processes. This is the level at which the learner generates some autonomy through a capacity to reflect upon his/herself and the events in his/her life. At the tertiary level, investigation becomes something of a moral science. It is concerned with the choices we make and how things, including ourselves, *could* be. Of course, such investigation can still be informed by knowledge of learning processes at the primary and secondary levels, as provided by the natural and social sciences.

At present, and perhaps reflecting our lack of understanding of consciousness, it is not easy to represent such a tertiary level of action in Figure 3. However, given the growing emphasis on learning autonomy in education, perhaps researchers working at the interface between neuroscience and education need to remain mindful that Figure 3 is a poor representation of what is actually a dynamic scenario of change and transformation. Furthermore, free will and reflexive self-determination may be a powerful and essential contribution to learning that requires careful consideration at all the levels (biological, cognitive, behavioural and social) represented here.

In summary, there is presently considerable interest and enthusiasm for the interdisciplinary venture that may be called neuroscience and education, although there are some immense challenges along the way and many of these derive from underlying philosophical issues within and between the two areas. These issues are not fatal in their implications, but initiatives attempting to integrate neuroscience and education would benefit greatly from explicit attendance to them, rather than running the risk of losing what is commonly understood as 'sense' by one or both of the communities involved.⁴

Correspondence: Graduate School of Education, University of Bristol, 35 Berkeley Square, Bristol BS8 1JA, UK.
Email: Paul.Howard-Jones@bristol.ac.uk

NOTES

1. Although sometimes absent from the name of the enterprise, it is worth noting that an understanding of the mind, as provided by psychology and/or cognitive science, is usually seen as essential in attempts to build conceptual bridges between neuroscience and education.
2. This anonymously derived expression is often used by popular writers about the brain but, for more accurate representations of the Hebbian learning theory it refers to, see Hebb, 1947.
3. Transcranial magnetic stimulation (TMS) is a noninvasive method to excite neurons, and selectively disrupt brain function, by applying rapidly changing magnetic fields.
4. The author would like to thank Paul Standish for his helpful comments on an earlier version of this article.

REFERENCES

- Alexander, H. A. (2006) A View from Somewhere: Explaining the Paradigms of Educational Research, *Journal of Philosophy of Education*, 40.2, pp. 205–21.
- Arbib, M. A. (2003) *The Handbook of Brain Theory and Neural Networks* (Cambridge, MA, MIT Press).

- Arshavsky, Y. I. (2006) The 'Seven Sins' of the Hebbian Synapse: Can the Hypothesis of Synaptic Plasticity Explain Long-Term Memory Consolidation?, *Progress in Neurobiology*, 80, pp. 99–113.
- Bennett, M. R. and Hacker, P. M. S. (2003) *Philosophical Foundations of Neuroscience* (Oxford, Blackwell).
- Blakemore, S. J. and Frith, U. (2000) *The Implications of Recent Developments in Neuroscience for Research on Teaching and Learning* (London, UCL, Institute of Cognitive Neuroscience).
- Brasil-Neto, J. P., Pascual-Leone, A., Valls-Sole, J., Cohen, L. G. and Hallett, M. (1992) Focal Transcranial Magnetic Stimulation and Response Bias in a Forced- Choice Task, *Journal of Neurology, Neurosurgery and Psychiatry*, 55, pp. 964–66.
- Bruer, J. (1997) Education and the Brain: A Bridge Too Far, *Educational Researcher*, 26.8, pp. 4–16.
- Bruner, J. S. (1972) *The Relevance of Education* (London, George Allen and Unwin).
- Bruner, J. S. (1974) *Beyond the Information Given: Studies in the Psychology of Knowing*, J. M. Anglin, ed. (London, George Allen and Unwin).
- Burns, K. and Bechara, A. (2007) Decision Making and Free Will: A Neuroscience Perspective, *Behavioral Sciences and the Law*, 25.2, pp. 263–80.
- Byrnes, J. P. and Fox, N. A. (1998) The Educational Relevance of Research in Cognitive Neuroscience, *Educational Psychology Review*, 10.3, pp. 297–342.
- Churchland, P. M. (2005) Cleansing Science, *Inquiry*, 48.5, pp. 464–77.
- Citri, A. and Malenka, R. C. (2008) Synaptic Plasticity: Multiple Forms, Functions, and Mechanisms, *Neuropsychopharmacology*, 33, pp. 18–41.
- Corkum, P. V., McKinnon, M. M. and Mullane, J. C. (2005) The Effect of Involving Classroom Teachers in a Parent Training Program for Families of Children with ADHD, *Child and Family Behavior Therapy*, 27.4, pp. 29–49.
- Crick, F. (1984) Memory and Molecular Turnover, *Nature*, 312, p. 101.
- Curtis, C. E. and D'Esposito, M. (2003) Persistent Activity in the Prefrontal Cortex During Working Memory, *Trends in Cognitive Sciences*, 7.9, pp. 455–463.
- Davis, A. J. (2004) The Credentials of Brain-Based Learning, *Journal of Philosophy of Education*, 38.1, pp. 21–36.
- Davis, H. P. and Squire, L. R. (1984) Protein Synthesis and Memory: A Review, *Psychological Bulletin*, 96, pp. 518–59.
- Degrandpre, R. (1999) Just Cause?, *The Sciences*, March/April, pp. 15–18.
- Delazer, M., Domahs, F., Barthä, L., Brenneis, C., Lochy, A., Trieb, T and Benke, T. (2003) Learning Complex Arithmetic—an fMRI Study, *Cognitive Brain Research*, 18, pp. 76–88.
- Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U. and May, A. (2004) Changes in Grey Matter Induced by Training, *Nature*, 427, pp. 311–12.
- Gazzaniga, M. S. (1995) Consciousness and the Cerebral Hemispheres, in: M. S. Gazzaniga (ed.) *The Cognitive Neurosciences* (Cambridge MA, MIT Press), pp. 1391–400.
- Geake, J. G. and Cooper, P. W. (2003) Implications of Cognitive Neuroscience for Education, *Westminster Studies in Education*, 26.10, pp. 7–20.
- Giesinger, J. (2006) Educating Brains? Free-Will, Brain Research and Pedagogy, *Zeitschrift für erziehungswissenschaft*, 9.1, pp. 97–109.
- Goswami, U. (2004) Neuroscience and Education, *British Journal of Educational Psychology*, 74, pp. 1–14.
- Goswami, U. (2006) Neuroscience and Education: From Research to Practice?, *Nature Reviews Neuroscience*, 7, pp. 406–13.
- Gureasko-Moore, S., DuPaul, G. J. and White, G. (2006) The Effects of Self-Management in General Education Classrooms on the Organizational Skills of Adolescents with ADHD, *Behavior Modification*, 30.2, pp. 159–83.
- Harré, R. (2002) *Cognitive Science: A Philosophical Introduction* (London, Sage).
- Hebb, D. O. (1947) *The Organization of Behavior* (New York, Wiley).
- Howard-Jones, P. A. (2007) *Neuroscience and Education: Issues and Opportunities*, *TLRP Commentary* (London, Teaching and Learning Research Programme).
- Howard-Jones, P. A.. (in press) Scepticism is Not Enough, *Cortex*.
- Kaufmann, L. . (2008) Dyscalculia: Neuroscience and Education, *Educational Research*, 50.2, pp. 163–175.

- McClelland, J. L. and Rogers, T. T. (2003) The Parallel Distributed Processing Approach to Semantic Cognition, *Nature Reviews Neuroscience*, 4, pp. 310–22.
- Martin, S. J., Grimwood, P. D. and Morris, R. G. (2000) Synaptic Plasticity and Memory: An Evaluation of the Hypothesis, *Annual Review of Neuroscience*, 23, pp. 649–711.
- Medawar, P. (1985) *The Limits of Science* (Oxford, Oxford University Press).
- Mel, B. W. (2002) Have We Been Hebbing Down the Wrong Path?, *Neuron*, 34, pp. 175–77.
- Miranda, A., Presentation, M. J. and Soriano, M. (2002) Effectiveness of a School-Based Multicomponent Program for the Treatment of Children with Adhd, *Journal of Learning Disabilities*, 35.6, pp. 546–62.
- Morton, J. and Frith, U. (1995) Causal Modelling: A Structural Approach to Developmental Psychopathology, in: D. Cicchetti and D. Cohen (eds) *Manual of Developmental Psychopathology* (New York, Wiley), pp. 357–90.
- OECD (2002) *Understanding the Brain: Towards a New Learning Science* (Paris, OECD).
- OECD (2007) *Understanding the Brain: Birth of a New Learning Science* (Paris, OECD).
- Parkinson, L. (2006) Boy's Behaviour 'Out of Control', *Bristol Evening Post*.
- Pinnegar, S. and Carter, K. (1990) Comparing Theories from Textbooks and Practicing Teachers, *Journal of Teacher Education*, 41, pp. 20–27.
- Schumacher, R. (2007) The Brain Is Not Enough: Potential and Limits in Integrating Neuroscience and Pedagogy, *Analyse & Kritik*, 29.1, pp. 38–46.
- Shastri, L. (2002) Episodic Memory and Cortico-Hippocampal Interactions, *Trends in Cognitive Sciences*, 6.4, pp. 162–68.
- Shaywitz, B. A., Shaywitz, S. E., Blachman, B. A., Pugh, K. R., Fullbright, R. K., Skudlarski, P., Mencl, W. E., Constable, R. T., Holahan, J. M., Marchione, K. E., Fletcher, J. M., Lyon, G. R. and Gore, J. C. (2004) Development of Left Occipitotemporal Systems for Skilled Reading in Children after a Phonologically-Based Intervention, *Biological Psychiatry*, 55.9, pp. 926–33.
- Snider, V. E. and Roehl, R. (2007) Teachers' Beliefs About Pedagogy and Related Issues, *Psychology in the Schools*, 44, pp. 873–886.
- Squire, L. R. (2004) Memory Systems of the Brain: A Brief History and Current Perspective, *eurobiology of Learning and Memory*, 82, pp. 171–77.
- Stevens, R. (1998) Trimodal Theory as a Model for Inter-Relating Perspectives in Psychology, in: R. Sapsford, A. Still, D. Miell, R. Stevens and M. Wetherell (eds) *Theory and Social Psychology* (London, Sage and the Open University).
- Tancredi, L. R. (2007) The Neuroscience Of 'Free Will', *Behavioral Sciences and the Law*, 25.2, pp. 295–2007.
- TLRP (2006) *Improving Teaching and Learning in Schools: A Commentary by the Teaching and Learning Research Programme* (London, TLRP).
- TLRP (2007) *Principles into Practice: A Teacher's Guide to Research Evidence on Teaching and Learning* (London, TLRP).
- Turkeltaub, P. E., Gareau, L., Flowers, D. L., Zeffiro, T. A. and Eden, G. F. (2003) Development of Neural Mechanisms of Reading, *Nature Neuroscience*, 6.6, pp. 767–73.
- Vaidya, C. J., Audtin, G., Kirkorian, G., Ridlehuber, H. W., Desmond, J. E., Glover, G. H. and Gabrieli, J. D. E. (1998) Selective Effects of Methylphenidate in Attention Deficit Hyperactivity Disorder: A Functional Magnetic Resonance Study, *Proceedings of the National Academy of Sciences (USA)*, 95, pp. 14494–99.
- Varma, S. and Schwartz, D. L. (2008) How Should Educational Neuroscience Conceptualize the Relation between Cognition and Brain Function? Mathematical Reasoning as a Network Process, *Educational Research*, 50.2, pp. 149–161.
- Vygotsky, L. S. (1978) *Mind in Society: The Development of Higher Psychological Processes*, M. Cole, V. John-Steiner, S. Scribner and E. Souberman eds (Cambridge, MA, Harvard University Press).
- Wegner, D. M. (2003) The Mind's Best Trick: How We Experience Conscious Will, *Trends in Cognitive Sciences*, 7.2, pp. 65–69.
- Wolfe, P. (1998) Revisiting Effective Teaching, *Educational Leadership*, 56.3, pp. 61–64.
- Wood, D., Bruner, J. S. and Ross, G. (1976) The Role of Tutoring in Problem Solving, *Journal of Child Psychology & Psychiatry and Allied Disciplines*, 17, pp. 89–100.