

A model for bridging the gap between neuroscience and education

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As the brain sciences make advances in our understanding of how the human brain functions, many educators are looking to findings from the neurosciences to inform classroom teaching methodologies. This paper takes the view that the neurosciences are an excellent source of knowledge regarding learning processes, but also provides a warning regarding the idea that findings from the laboratory can be directly transposed into the classroom. The article proposes a model of five levels which describe different types of knowledge that must all contribute to new teaching methodologies. These include the levels of neuroscience, cognitive neuroscience, psychology, educational theory and testing, and finally the classroom.

Before diving into the debate regarding the degree to which the fields of neuroscience and education are, can be and should be interrelated, we can acknowledge the current movement towards the development of a new field where the two subject areas work in close alignment with a common goal of developing teaching methods supported by knowledge of the mind and brain. This can be seen internationally in projects ranging from the OECD's (Organisation for Economic Co-operation and Development) examination of education in the context of brain based studies to Harvard University's establishment of a master's programme entitled 'Mind, Brain and Education' with an associated journal. This development also has a strong UK element composed of the University of Cambridge's Centre for Neuroscience in Education, Oxford's Cognitive Neuroscience and Education Forum, and several additional frameworks for bringing neuroscientists, psychologists and educationists together in the form of conferences and special interest groups. Although the neurosciences have been asking questions related to how humans learn for decades (Gazzaniga, 2004; Willingham & Lloyd, 2007), there is a clear movement at hand to formalise this connection. Several academic areas such as biology, genomics, psychology and

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linguistics are also accepted in the fold but the prevalence of the neurosciences and education become evident when examining the names that have thus far been thrown into the ring for the name of this new hybrid field. These include 'Neuroscience and Education' (Goswami, 2004), 'Neurolearning' (Bruer, 2003) and 'Educational neuroscience' (Pettito & Dunbar, 2004).

Opinions among academics vary greatly in regard to the utility of this partnership. While Davis (2004) states that medical models of cognition 'have only a very limited role in the broader field of education and learning' mainly because learning related intentional states are not internal to individuals in a way which can be examined by brain activity, Pettito and Dunbar (2004) are at the other end of the spectrum as they find that this new discipline 'provides the most relevant level of analysis for resolving today's core problems in education.' Others already look at education in cognitive terms, saying that 'the purpose of formal education is to maximise the reinforcement of connections between relevant functional modules' (Geake, 2004). Opinions of other academics addressing the question fall throughout this range (Bruer, 1997; Goswami, 2004; Ansari & Coch, 2006; Wasserman, 2007; Willingham & Lloyd, 2007). When teaching professionals were surveyed in regard to their opinion on the matter (Pickering & Howard-Jones, 2007), they replied that they were generally enthusiastic concerning the use of neuroscientific findings in the field of education, and that they felt these findings would be more likely to influence their teaching methodology than curriculum content. Whether or not this will be the case, it is clear that the topic is one that is currently attracting a great deal of attention and debate.

This paper supports the idea that the neurosciences have a role to play in education, but emphasises the distance and the complex relationships that exist between the brain sciences and proven teaching methods ready for the classroom. It is highly doubtful that any single given study in neurology will have a direct application to the classroom but, on a more hopeful note, it is almost certain that aggregations of findings from several studies, mediated through higher levels culminating in the behavioural and educational levels will indeed provide new teaching methodologies. However, these proposed methodologies are not the final step in the journey, but only the beginning of a new one as new methodologies undergo rigorous testing in the classroom in order to allow for their efficacy to be judged. It will not suffice to assume that once neuroscientific results are established they can be easily transferred directly into the classroom. The warning must even be made that the oversimplification of this relationship risks placing pressure upon educationists to adapt what is known about particular topics at the neurological level into teaching programmes far too early, thereby creating ineffective new pedagogies called 'brain-based' but lacking a legitimate evidence base. In consideration of the complex relationship spanning the laboratory and the classroom, this paper proposes a model describing the many levels of research that are likely to be involved for educational goals to be obtained. This is not the first model examining the pathway between neuroscience and education but it is set apart from the rest in the nature of its proposed levels and its balance between the provision of both warning and encouragement.

A possible fear that people may harbour in relation to the development of this relationship may be the impression that the brain sciences are declaring hegemony over a process that should be more holistic, encompassing the whole human instead of reducing the act of learning to change in a collection of neurons. Furthermore, it may appear from some current discussions that findings from a neurology laboratory are seen as independent truths, responsible to no one and disconnected from the history of teaching and learning. Here, the point must be made that the neurological is listed as the starting point of this model, but that the brain sciences are here seen as being linked with other fields around them not explicitly represented in this model, such as philosophy, anthropology and history. In addition, methodologies developed in conjunction with physical brain-based studies need not become the basis of all education, but only one very useful source that educators use when appropriate alongside methodologies from other sources.

The main point that must be highlighted is the impossibility of moving straight from the laboratory to the classroom. If the brain sciences are seen as the fount of all knowledge, then it is not surprising that the impression might be given that neuroscience will even tell educators how to teach. This impression must be changed in order for the fields of psychology and education to fulfil their mandatory roles of developing and testing theories of learning. A comparison could be made with a restaurant, where neurological research is likened to a prepared meal about to be served to a table of students, with educators playing at best the role of waiters delivering the meal. According to the point being made here, brain-based research would more aptly be seen as raw ingredients being delivered to the restaurant. In this new model, the educationalists are working hard in the kitchen, experimenting with the ingredients, developing and testing new recipes in order to serve a meal to the final consumer, the learner.

This paper proposes that the path bridging education and the neurosciences is a complex one, with various steps connecting the two ends. A model of this path is presented in Figure 1. Five basic levels are offered in the model, the levels of *neuroscience*, *cognitive neuroscience*, *psychological mechanisms*, *educational theory*, and finally the *classroom*. For effective teaching methods which are based on neuroscientific findings and which are supported by a scientific evidence base, most or all of these levels of work, and possibly more in some cases, are necessary to their development.

It is useful to make the distinction between *neuroscience* per se and the related field of *cognitive neuroscience*. Whereas neuroscience concentrates on the cellular level of the brain, cognitive neuroscience focuses on brain function and architecture (Gazzaniga, 2004) or, in other words, how collections of cells function together in order to form mechanisms that are responsible for precise activities such as speech perception, word retrieval or working memory. Pure neuroscience concerns itself with topics such as information transfer mechanisms within and between cells carried out electrically and chemically. This information is relevant to all aspects of the nervous system. Cognitive neuroscience, on the other hand, takes as its object of interest configurations of neural activity directly underpinning cognition. This focus on better understanding cognition also distinguishes between these two levels. Neural mechanisms

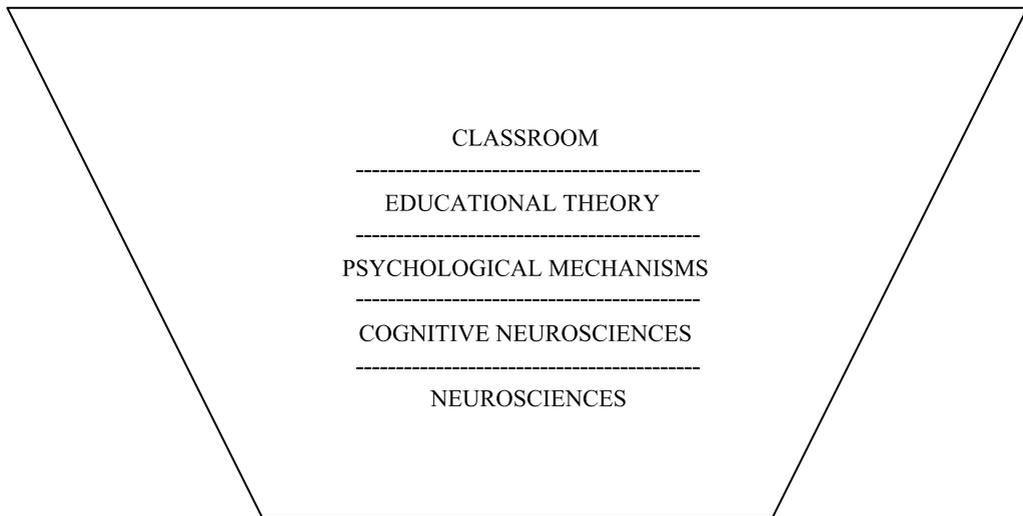


Figure 1. Model of levels of development

underlying cognition could, for example, be a particular configuration of neurons found to act simultaneously when presented with an auditory stimulus such as a given phoneme or a visual stimulus such as a change in colour of a screen from blue to red. With this distinction between pure and cognitive neurology having been made, it is possible that some of those sceptical of the use of pure neurological knowledge in education will see the connection between cognitive neuroscience and education. Goswami (2004) puts this aptly when saying ‘Both educationists and neuroscientists are interested in learning and how to optimise learning.’ The remaining questions are therefore whether findings from cognitive neuroscience can actually be useful in the classroom and if so, how?

The next level of analysis is that of *psychological mechanisms*. These mechanisms are similar to those discovered at the level of cognitive neuroscience, but can be distinguished from them by considering them not to be physical entities, but instead functional ones. This distinction follows the same lines as the distinctions between the physical brain itself and the more theoretical entity often referred to as the mind. Ideally, researchers at the cognitive neuroscience and psychological mechanism levels would work closely, attempting to match the physical actions of neural groups with psychological mechanisms that underpin or act as subcomponents of cognition. Examples of this would include neural groups that are the physical manifestation of mechanisms such as attention, various forms of memory, or possibly a deductive reasoning capacity.

It must be mentioned that the divide between the cognitive neuroscience level of mechanisms and the psychological, functional level of mechanisms is likely to be an artificial one, a product of our time which exists due to the fact that the vocabularies between the physical and the functional sides appear to be at different levels (because researchers have not yet discovered how to translate psychological terms into biolog-

ical terms (and vice versa) (Byrnes & Fox, 1998). This implies that the separation between the terms *brain* and *mind* could perhaps more appropriately be seen as different perspectives of the same thing, much like the famous figure / ground images where a viewer can see either an old lady with a large nose or a young woman's profile. Both levels have been included in this model for the time being due to the historical separation between these notions of the physical and the functional.

Next in this model, research would progress to the *educational theory* level where theorists would develop possible teaching and learning theories based upon work stemming from the neurological and psychological levels and their own specialised knowledge of teaching and learning. This may involve the discovery of subcomponents of various cognitive tasks that the children are carrying out which would in turn allow educational theorists to develop teaching strategies that emphasised these components. This activity may also allow close examination of the performance of students who are having difficulty with that task, leading to specific applications of this knowledge to students with special educational needs.

Another task to be addressed at the educational theory level is an examination of current teaching practice in the light of proposed and established cognitive mechanisms. It would be inappropriate to expect that all teaching practices in schools should be based on the lower levels of this model, but it would be wholly suitable to investigate teaching methods which may actually conflict with them.

Yet another task for educationists at the educational theory level is to carry out rigorous testing of the developed hypotheses in order to judge the efficacy of the proposed new methods compared to current ones. Only when shown to be successful (and another task at this level would be making decisions regarding how success would be appropriately measured) might the methods be found appropriate for the *classroom* level. Again, it must be emphasised that it is not being suggested that this is the route that all classroom teaching should follow; instead it is a rough estimation of the long and complex road that is likely to exist between findings from brain observation and the use of these findings in classrooms.

The final step represented in the model is that of the *classroom* where the new teaching methodologies are implemented. At this stage, there should be close monitoring in order to ensure that teaching shown to work at the earlier level is successful. The earlier example of the restaurant can now be revisited. The classroom level is the closest to the waiter in the restaurant delivering the food to the diners. However, the waiter's role in this restaurant goes far beyond placing the food on the table. Instead, it is the waiter's role to interact with the diners in order to figure out whether or not the meal is welcomed by the diners and whether the meals are actually nourishing and enjoyable. This information must then be fed back to the kitchen for further evaluation. This level is much more than a recipient of the knowledge stemming from other levels of the model but is instead an active component of the research. It is about the delivery of teaching programmes developed at the earlier level as well as a testing ground providing evidence for failures and successes alike.

This model is of course a simplified version of what would go on in reality. This model may have a tendency to be seen as a linear one, with information flowing in an

upwards direction, but in reality, information must travel up and down the system and may bounce back and forth between different levels several times before moving on to another. In addition, many overlapping strings of research in the same area are likely to be going on at the same time, making all areas in the model active at the same time. The model might be more accurately seen in the form of a pinball machine with several balls on the go at the same time, having five levels that must be completed to attain the jackpot. Also interesting to note is that each level of the model does not link exclusively with one type of professional. Some research papers situated at the level of cognitive neuroscience make suggestions in regard to educational theory and research projects are regularly carried out between professionals from different layers of this model. Although this may confuse the question of who does what, it also assists the flow of information between levels.

Considering that those working at the top of the model presented in this paper will be working with concepts derived from the bottom, educational theorists will be helped by having a grounding in the techniques used by the neurosciences to gather experimental information. Although educators and educational theorists will be familiar with the idea of neuroimaging, they are less likely to be aware of the tools used and the difficulties met by researchers in examining the brain. The goal of these tools is to see the brain in action, but different tools have different capabilities which allow for different possibilities. Therefore, a brief description of some of the main tools used in brain research follows.

Before looking at individual machines that can monitor brain activity, they will be categorised into two main groups; one giving primarily spatial information that shows precise locations of where activities are being carried out in the brain and the second giving primarily temporal information providing precise timings of when things in the brain are happening. Both types of information are important. Spatial information not only provides information about what area of the brain is active during certain activities, but can also inform us about distinct regions working at the same time, perhaps in partnership. On the other hand, high temporal resolution allows the reconstruction of brain activity on a millisecond by millisecond basis which is vital considering that brain processing is carried out on such a timescale. Unfortunately, machines tend to have either high spatial or high temporal capabilities and not both, thereby making it difficult to capture the whole picture of what's going on with a single machine.

The main tools used in cognitive neuroscience research that provide strong spatial resolution are the fMRI (functional Magnetic Resonance Imaging) and PET (Positron Emission Tomography). Both provide images of the working brain, but using different sources of measurement. In a PET scan, a radioactive isotope is injected which allows the amount of glucose being metabolised in the brain to become visible. The metabolisation of glucose is indicative of the amount of blood in each part of the brain which in turn represents brain activity. As a part of the brain becomes more active, blood flow to the area increases and more glucose is used. The need for radioactive material, the high cost of use and its poor temporal resolution are all disadvantages but it gives high quality visual images (Otte & Halsband, 2006).

The fMRI shows the brain by measuring blood flow in the brain. Again, higher blood flow indicates greater neural activity in the brain. The fMRI performs better on both the spatial and temporal fronts than the PET scan and is less expensive to operate. A major drawback is the amount of noise that it creates, making it inappropriate for certain types of studies.

The EEG (electroencephalogram) and the MEG (magnetoencephalogram) are both popular methods with high quality temporal resolution with measurements based on milliseconds. Neither gives images of the brain, but instead detailed information about the time course of neural activity. Both give indications of where brain activity is being carried out, but not to the same degree as the instruments described above. The EEG shows cortical activity of the cortex in the form of electrical signals directly harvested from groups of thousands of neurons through electrodes placed on the scalp while the MEG measures the magnetic field outside the brain caused by electrical activity. The EEG has advantages in mobility and price while the MEG has an advantage in spatial resolution.

One major force in the development of equipment supporting cognitive neuroscience is the attempt to pair tools in order to combine precise spatial and temporal information, an action known as ‘multimodality data fusion’ (Horwitz & Pöppel, 2002). If successful, this will allow researchers to observe brain activity in real time with excellent spatial resolution as well.

A difficulty in neurological studies which include ‘watching’ a particular activity is the inherent difficulty of isolating a single behaviour. For example, watching someone’s brain while they read will show that a great deal of the brain is used. When the researcher comes to break down the act of reading in order to locate the part of the brain that supports the visual recognition of word shapes, it may be difficult to separate brain activity carrying out this activity from brain activity required in the recognition of individual letters. Therefore, very exacting experimental conditions are necessary in learning about complex activities.

A way around the difficulties of analysing brain activity during multilevel tasks is through use of the technique of subtraction. This allows the researcher to identify the brain’s activity during a relatively isolated task, such as letter identification in the case above, and then to subtract this activity when looking at the more complex activity, single word identification in this example, giving a clearer picture of what parts of the brain are used in word identification above and beyond letter identification.

One further type of tool available to the researcher studying brain activity falls under the category of lesion studies. Individuals who have brain damage in a defined area can be useful for researchers studying the relationship between damage to that area and any ensuing functional changes. For example, people with aphasia have often been studied in order to better understand which parts of the brain control various linguistic abilities (Naeser *et al.*, 1982; Zurif *et al.*, 1993; d’Esposito & Alexander, 1995; Kreisler *et al.*, 2000). An important difficulty in using lesion studies is that any given brain injury is unlikely to match up with another person’s injury to be compared and it is also unlikely that the borders of a brain lesion will correspond with a distinct anatomical and/or functional brain region.

With better understanding of the tools and methods used in the cognitive neurosciences, the alignment of areas accessible to the neurologist and of interest to the educator becomes more visible. While few if any would suggest that human learning can be neatly broken down into smaller, mutually exclusive building blocks, most would agree that several elements underlying the learning processes can be studied in neural terms. That is not to say that findings from the neural studies will provide exhaustive answers about the nature of a particular learning mechanism, but instead that such findings are likely to provide important and useful pieces of the puzzle.

The fact that the call for connections between neuroscience and the classroom is still being made highlights the current state of disconnection between the two. However, an attempt will now be made to show past research that roughly follows our model, although not every step has been carried out to the full extent that could be considered as ideal. Much like in the shape of the model presented in this article, particular teaching recommendations correspond to the apex of the shape while a very broad neurological basis provides the foundation. The educational area followed in this example is that of reading pedagogy as presented by Adams (1990). For the sake of clarity, the model will be presented beginning at the level of educational theory.

Adams presents a system of teaching pedagogy based on explicit instruction in letter to sound correspondence in an attempt to establish the alphabetic principle. According to her programme, regular correspondences should be taught first and only when these are comfortably established should alternate correspondences be taught. Aspects of phonological awareness such as phoneme, syllable and word awareness are seen as vital prerequisites.

Adams draws clear connections between her work at the educational theory level and the model of Parallel Distributed Processing (PDP) put forward by McClelland and Rumelhart's seminal work (1986) which corresponds to the level of the psychological mechanism in this paper's model. Main tenets of PDP include the view of the system as a serial as opposed to a linear processor and the notion that the mechanism is made up of interconnected units whose connection strengths change based on experience, thus allowing the system to learn. Adams uses these notions to build a notion of reading based on orthographic, meaning-based and phonological processing, all of which are carried out in a coordinated fashion.

Adams explicitly refers to the PDP foundations in her description of single word processing, emphasising the network formed between units in the system. This is most clearly demonstrated in her portrayal of orthographic processing:

... when the reader fixates on the word *the*, all three of its letters lie in full foveal view. Because of this, the units corresponding to each of its letters receive direct visual stimulation at once. In turn, all of these units simultaneously receive and pass excitation to each other at once. Thus, not only does the *t* help the *h*, but the *h* helps the *t*, and similarly for the *e*. In this way, the whole word is truly more perceptible than the sum of its parts. (1990, p. 110)

Through this depiction of reading, Adams makes clear that although advanced readers recognise words as entire entities, they can only do this from their knowledge of

letter to sound correspondences and thus she uses information of this type to build a programme of reading pedagogy.

McClelland and Rumelhart's development of the PDP model is in turn supported by their strong knowledge of neural systems, both at the cognitive and cellular levels. It is difficult to trace a direct lineage from individual studies from the neurological levels to their design given the wide range of influences to which they refer. Indeed, so great is the contribution of the neurosciences to their design of psychological mechanisms, that they devote over 200 pages of their seminal work to a description of relevant biological mechanisms.

Now that the middle and bottom of the model have been explored, the apex of the model can be rejoined. Adams' ideas were put into the classroom level in a reading and writing programme entitled 'Collection for Young Scholars' which was in turn critically examined by a research study which compared her programme to two other types of reading pedagogy, one which employed less direct instruction in the alphabetic principle and another which used incidental instruction of the code (Foorman *et al.*, 1998). Results found that the first and second graders (children from five to seven years old typically) made the greatest improvements in decoding skills and overall word reading using Adam's method of direct phonics instruction. This is one of the rare occasions where it is possible to trace the relationships, at least roughly, of a specific teaching methodology to all of the levels of the model presented in this paper. Although controversy continues to exist regarding which methods of teaching create the best readers, this is an admirable example of an attempt to base these methods within the framework of a scientific evidence-base and to continue the evaluation of the method after its application in the classroom.

The neurosciences have the ability to provide information in several areas underpinning human learning processes. These include attention, memory, basic and higher processing of all sensory information, reasoning, and language processing and this list is not exhaustive. A major goal is to use raw data produced by brain activity to develop hypotheses regarding the functional architecture of the brain, complete with first an understanding of what types of mental mechanisms exist that allow us to think and learn and second a knowledge of how these mechanisms work and interact. Great challenges lie ahead on this path and our complex brains do not give up their secrets easily.

One of the greatest hopes for educational findings from the neurosciences is in the field of special educational needs where very large numbers of children and adults are affected by difficulties affecting their education such as specific language impairment (Leonard, 1998), dyscalculia (Shalev *et al.*, 2000) and dyslexia (Shaywitz, 1998). It is hoped that further research in the brain sciences will allow screening and effective educational support for people with these difficulties. These studies should simultaneously provide us with further knowledge of the typically developing brain. For example, gaining greater insight into what is happening in the brain of a person with dyslexia also provides information about what happens in the brains of typically developing readers. In the same vein, hopefully what is learned about the provision of educational support for individuals with dyslexia will provide insight into pedagogy for other readers as well.

It is evident that the more closely a study moves towards 'classroom' in this model, the greater number of elements from the other levels are present within it. Already, studies at the cognitive level have elements of the neurological and most have elements of the psychological as well. The example of the educational level is most telling in that it encompasses all of the other elements below it. It is again important to acknowledge the fact that other subject areas not listed in the model, such as linguistics, play an important role as well. Although the levels in this proposed model are not discrete ones, we suggest that they may allow a clearer look at the complexities involved in moving towards the development of teaching strategies stemming from the brain sciences.

Conclusion

Although reading is the only cognitive activity discussed in any depth in this article, promising steps are being taken in a variety of other educationally related fields. PET, EEG and fMRI studies are probing the brain's ability to carry out reasoning, asking the questions such as whether deductive reasoning is based on a set of mental logic rules (Braine, 1978) or visual mental models (Johnson-Laird & Byrne, 1992) and whether deductive and probabilistic reasoning have shared or separate mechanisms (Osherson *et al.*, 1998; Goel & Dolan, 2001; Parsons & Osherson, 2001).

In the field of bilingualism, brain scanning has shown there is a difference between bilinguals who learn a second language before age five and those who learn a second language at a later age. The first group processes their two languages in overlapping left hemisphere language centres while the second group calls more upon right hemisphere zones, working memory and inhibition areas when using their second language (Perani *et al.*, 1996; Kim *et al.*, 1997; Weber-Fox & Neville, 1999; Wartenburger *et al.*, 2003) (see Pettito & Dunbar, 2004 for an in-depth discussion).

In mathematics, Dehaene *et al.* (1999) used fMRI to distinguish whether precise mathematical calculations and numerical estimations used identical or distinct brain areas. A dissociation was shown to exist which also allowed the researchers to postulate that linguistic systems were likely to be mediating the precise calculations while visual centres were implicated in the approximations.

The findings from the research projects above and from hundreds of others like them add to the growing hope that a great deal of potential exists regarding the formation of a new era where the brain sciences will be a useful partner in improving our knowledge and implementation of education.

It is likely that the first serious implementations of new educational methods based on brain studies will be in the field of special education. There is a great deal of research that compares the brains of typically developing children with the brains of children with some type of learning difficulty such as dyslexia, dyscalculia or specific language impairment. Comparative research of this type allows researchers to learn not only about differences between the brains, but also provides insight into the typical processes of activities like language processing. However, the large number of children whose education is being negatively affected by difficulties such as language

impairment makes the area of special needs likely to be given priority, and appropriately so. Large-scale projects coordinating several lines of research promise hope for new breakthroughs. For example, the current NeuroDys project involves 13 research groups from 10 European countries working with concerted effort to discover the etiology of dyslexia with research being carried out from genetic, environmental and neuroscientific perspectives. The planned impact of the programme is not only to find the cause and nature of dyslexia, but also to provide information which will be useful to developing screening tools and treatment (Bosch, 2006).

Although bodies of neurological research are developing in several different areas related to cognition and education, it cannot be overemphasised what early days we are in. It is even unclear as of yet what types of examination of the brain are important in carrying out the most informative studies. For example, different measures of the physical brain such as grey matter volume (Wilke *et al.*, 2003; Haier *et al.*, 2004) and grey matter density (Frangou *et al.*, 2004) were investigated in relation to IQ before it was found that the rate of change of the thickness of the cortex, rather than the measure of thickness itself, at particular ages is most closely related to IQ (Shaw *et al.*, 2006). Examples such as this show that it can take several years, read decades, to establish the very foundations of the new science of evidence-based education. Ansari (2005) points out the necessity of this realisation, saying that ‘There is currently a strong emphasis on the need for research findings to be both immediately available, and directly applicable to the classroom. This inadvertently sets high expectations which, if not met, could lead to the quick erosion of this developing field.’

Besides the work to be done at the neurological level, in order to move from the laboratory to the classroom a vast amount of research will need to be carried out in the field of educational practices. This work will be most useful if done in a multi-level discussion. It has been suggested that educationists could feed into cognitive neuroscience research through the provision of behavioural data on children and by clarifying the questions they find most pressing (Geake, 2005). Some of these questions might involve the recognition of learning difficulties, the nature of verbal and non-verbal reasoning, and how much variation exists between how typically developing individuals learn. The road from the laboratory to the classroom may be a longer one than many realise, but given the possible benefits, it is certainly one worth travelling.

Notes on contributor

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