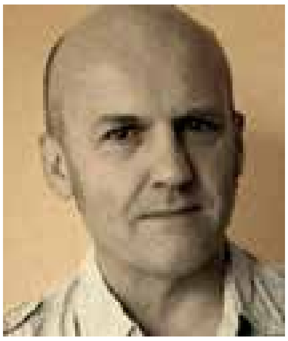
MINDS, BRAINS AND LEARNING GAMES



PAUL A. HOWARD-JONES

Graduate School of Education, University of Bristol

Dr Paul Howard-Jones (Graduate School of Education, University of Bristol) researches at the interface between neuroscience and educational theory, practice and policy, and he publishes in all associated areas. In 2010 he published one of the first textbooks for researchers in this area, and his commissioned work includes a review of the effects of technology on the brain, which he launched at the 2011 Nominet Lecture at the UK's Royal Society for Arts. His scientific research combines neurocomputational modelling with functional brain imaging in order to explore the relationship between reward and learning. Technology based on this work is already being used to support learning in 20 different countries across the world. He was a member of the UK's Royal Society working group on Neuroscience and Education that published its report in 2011. He has led the development of a new postgraduate (MSc) course in Neuroscience and Education at the University of Bristol that will launch in October 2013.

In a previous life, he worked as a schoolteacher, trainer of teachers and as an inspector of schools.

ABSTRACT

National and supra-national initiatives, as well as the launching of associated journals and postgraduate courses, suggest that neuroscience is becoming a new source of insight for education. In the last decade, neuroscientific evidence has informed many educational debates, including approaches to early numeracy and literacy, the financial returns for educational investment and our understanding of a range of learning disorders. In the future, the educational impact of neuroscience may prove greatest where another force for change, technology, is already transforming how we learn. Insights from neuroscience are helping to explain why video games are so engaging and research suggests that, unlike most other types of technology, they may be a 'special' environmental influence. The same neural and cognitive processes appear to underlie both the hazard and the educational potential of video games, highlighting the need for a scientific understanding of these processes to ensure they benefit, rather than disrupt, our children's education and development. Recent interdisciplinary research at the University of Bristol has investigated the neural mechanisms of gaming, their relationship to learning and how gaming influences learning processes in the classroom. This work has now resulted in a free app for teaching through gaming that is being used in 20 countries across the world.

The dialogue between neuroscience and education is still in its infancy and many challenges remain for those seeking to integrate insights from brain science into educational thinking. The history of so-called 'brain-based' learning, with its unscientific and unevaluated concepts, suggests there are many pitfalls. It also emphasises the need for a research-based transdisciplinary approach that assures optimal outcomes in terms of scientific validity and educational relevance.

HOW CAN WE USE INSIGHTS FROM NEUROSCIENCE TO HELP US TEACH AND LEARN MORE EFFECTIVELY?

The last decade has seen something of a step change in efforts to bring cognitive neuroscience and education together in dialogue. This may partly be due to anxieties over the 'parallel world' of pseudo-neuroscience found in many schools. Many of these concepts are unscientific and educationally unhelpful, and there is clearly a need for serious 'myth-busting'.

There are currently no cognate forums to scrutinise and clearly communicate messages combining scientific and educational understanding to teachers. In their absence, neuro-myths have flourished. We surveyed 158 graduate trainees about to enter secondary schools (Howard-Jones, Franey, Mashmoushi & Liao, 2009):

- 82 per cent considered teaching children in their preferred learning style could improve learning outcomes. This approach is commonly justified in terms of brain function, despite educational and scientific evidence demonstrating the learning style approach is not helpful (Kratzig & Arbuthnott, 2006).
- 65 per cent of trainees considered that co-ordination exercises could improve integration of left–right hemispheric function.
- 20 per cent thought their brain would shrink if they drank less than 6–8 glasses of water a day.

None of these ideas is supported by what we know from scientific studies (for review, see Howard-Jones, 2010).

There may, however, be a more positive reason that discussions are breaking out between neuroscience and education. Ideas are now emerging from authentic neuroscience with relevance for education. Neuroscience has helped identify 'number sense' (a non-symbolic representation of quantity) as an important foundation of mathematical development and associated with a specific region of the brain called the intraparietal sulcus (Cantlon, Brannon, Carter & Pelphrey, 2006). As we learn to count aloud, our number sense integrates with our early ability to exactly represent small numbers (1 to 4) to 'bootstrap' our detailed understanding of number. Such insights have prompted an educational intervention yielding promising results (Wilson, Dehaene, Dubois & Fayol, 2009). In reading, children with developmental dyslexia have shown reduced activation in typical left hemisphere sites and atypical engagement of right hemisphere sites, with consequent educational interventions improving language outcomes and remediating these differences in neural activity (Shaywitz et al., 2004; Simos et al., 2002; Temple et al., 2003). Neuroscience is also shedding light in other areas of education, providing insight into the link between exercise and learning (Hillman, Erickson & Framer, 2008), and prompting re-examination of teenage behaviour (Blakemore, 2008). Perhaps as importantly, it is now established scientists who are promoting neuroscience as having educational value (for example, Blakemore & Frith, 2005; de Jong et al., 2009; Goswami, 2004). Indeed, neuroscientists appear increasingly willing to speculate on the possible relevance of their work to 'real world' learning, albeit from a vantage point on its peripheries. Such speculation often comes under the heading of 'educational neuroscience' – a term that broadly encompasses any cognitive neuroscience with potential application in education. Accordingly, its research basis might be characterised by the epistemology, methodology and aims of cognitive neuroscience. But moving from speculation to application is not straightforward, since the educational value of insights from neuroscience rest on their integration with knowledge from more established educational perspectives.

There are many challenges in moving from brain scan to lesson plan, as we seek relationships between neural processes and the types of complex everyday learning behaviours we can observe in schools and colleges. To begin with, we have to draw together at least three very different types of evidence: biological, social and experiential. (Here, all observations and measurements of behaviour, including those collected in the laboratory, are classified as essentially social in nature, since even pressing buttons must be interpreted in the context of the instructions provided by the experimenter.) One thing appears clear from the outset: a simple transmission model in which neuroscientists advise educators on their practice should never be expected to work. Neuroscientists are rarely experienced in considering classroom practice. Since neuroscience cannot provide instant solutions for the classroom, research is needed to bridge the gap between laboratory and classroom. To emphasise the key role of educational values and thinking in the design and execution of such a venture, workers at the University of Bristol have found themselves using the term 'neuroeducational research' to describe this enterprise (Howard-Jones, 2010). For both scientists and educators, co-construction of concepts requires broadening personal epistemological perspectives, understanding different meanings for terms used in their everyday language (for example, learning, meaning, attention, reward, and so on) and appreciating each other's sets of values and professional aims. This boils down to having a dialogue about how the different perspectives and their favoured types of evidence can inform about learning in different but potentially complementary ways. In contrast to such authentic interdisciplinary work, brief intellectual liaisons between education and neuroscience are never likely to bear healthy fruit. These flirtations may, indeed, spawn further neuro-myth, often due to a lack of attention to psychological concepts. A common example is when synaptic connections in the brain are used to explain how we form connections between ideas. This conflation of brain and mind allows some educational practices to gain an apparently neuroscientific flavour. (Published research shows that explanations provide greater satisfaction when they include neuroscience, even when the neuroscience is irrelevant (Weisberg, Keil, Goodstein, Rawson & Gray, 2008)). In reality, however, association between ideas is a well-studied psychological concept, and is currently impossible to study at the level of the synapse.

Having this important conversation about how different perspectives inform learning is a first step towards a theoretical framework for research at the interface of neuroscience and education. This can help us to combine findings more judiciously across perspectives to develop a better understanding of learning (see 'Mapping the power of different perspectives', below), but such an aspiration also has implications for methodology. If there is a genuine commitment to interrelate findings from component perspectives, then the methods associated with these perspectives can be adapted to better support such interrelation. For example, qualitative interpretation of classroom discourse can draw usefully on neurocognitive concepts in the interpretive analysis of its meaning. Some brain imaging studies can contribute more meaningfully to the construction of neuroeducational concepts if they include semi-structured interviews of participants to derive experiential insights about their constructs, strategies and attitudes. In some bridging studies, judicious compromise and innovative approaches may help improve the ecological validity of experimental tasks while still attempting to control extraneous variables. Perhaps most unusually, researchers in the same team may find themselves sequencing radically different methods to collect biological, social and experiential evidence as they attempt to construct answers that, collectively, help span the social–natural science divide.

MAPPING THE POWER OF DIFFERENT PERSPECTIVES

Mind is an essential concept for linking brain and behaviour, including learning behaviour. That makes psychology, as the study of mind, crucial to neuroeducational research, as it is to cognitive neuroscience. When we consider two brain-mind-behaviour models interacting within a social environment as shown in Figure 1, we can start reflecting on the complex interaction between cognitive, neural and social processes that can arise when behaviour becomes socially mediated. Social complexity remains chiefly the realm of social scientists, who often interpret the meaning of human communication in order to understand the underlying behaviour. The dotted lines represent bi-directional influence, emphasising the extent to which the social environment (including educational environments) influences neural learning processes and brain development (as studied in the natural sciences), as well as vice versa.

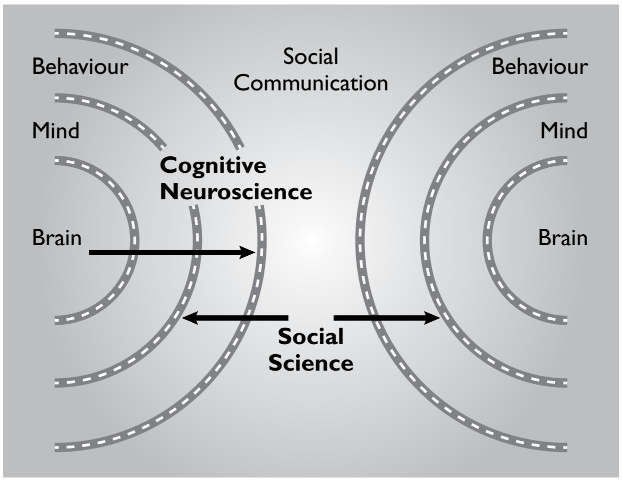


Figure 1 Two brain-mind-behaviour models (from P. A. Howard-Jones (2007), *Neuroscience and education: Issues and opportunities*, London, UK: Teaching and Learning Research Programme)

The unusual sequencing of methods in neuroeducational research is here illustrated by a set of investigations involving our lab (NEnet at http://www.neuroeducational.net).

LEARNING GAMES

Video games are very engaging. Neuro-imaging has revealed they stimulate our brain's reward system as much as methylphenidate (Ritalin) and some amphetamines (Weinstein, 2010). This response, involving dopamine uptake in the mid-brain region, is not just associated with attention but also with synaptoplasticity (the brain basis of learning) in a range of cortical regions (Shohamy & Adcock, 2010). This may help explain why action video games enhance a range of cognitive functions (Bavelier, Green & Dye 2010) and can also teach affective response, whether this involves the teaching of empathy via pro-social gaming or our aggressive tendencies via violent video games (Howard-Jones, 2011). Unsurprisingly, the power of video games to achieve these changes is itself becoming a focus of neuroscience research (Bavelier, Levi, Li, Dan & Hensch, 2010).

Video games provide a very rapid schedule of rewards but, importantly, these rewards are usually uncertain: that is, their arrival is mediated by some element of chance. Reward uncertainty is a feature of all games, and this helps to explain their attractiveness. The predictability of an outcome has been shown to influence the reward signal it generates in the brain, with maximum response for rewards that are halfway between totally unexpected and completely predictable: that is, 50 per cent likely (Fiorillo, Tobler & Schultz, 2003). This has been used to explain why humans love games of chance (Shizgal & Arvanitogiannis, 2003). Our research investigated the relevance of such neural concepts in educational games, and it began with a series of bridging studies. Firstly, we tested a hypothesis generated from the science, and demonstrated that students preferred educational tasks when they were embedded in a gaming context involving uncertain rewards (Howard-Jones & Demetriou, 2009). A second classroom study revealed how reward uncertainty subverted the discourse around learning in positive ways, encouraging open motivational talk of the type found in sport. A further study compared the physiological response of adults carrying out a learning task with and without chance-based uncertainty, and showed that reward uncertainty heightened the emotional response to learning.

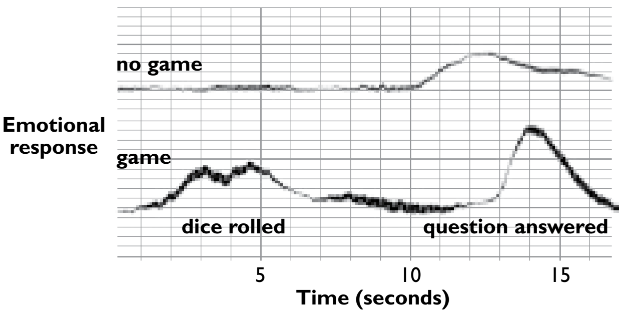


Figure 2 Emotional response and reward uncertainty

Our attraction to reward uncertainty may explain our interest in games but, when encountered in a learning game, it can also transform our emotional response to learning. In a laboratory experiment, adult participants competed with a computer in a learning game. To win points, they had to throw two dice and, to keep the points they scored, answer the subsequent question. Figure 2 shows a typical response of a participant experiencing a 'no game' condition (in which each die was stuck on '3') and a 'game' condition in which the dice were free to move. In the game condition, a greater emotional response was generated for throwing the dice *and* for answering the question.

But, to understand how the response of the brain's reward system influences learning from one event to another in a learning game, it was necessary to apply a neurocomputational model. In this type of approach, a computer program is built that mimics how our present understanding of the brain might predict behaviours such as decision making. Essentially, it is just a more sophisticated version of having a hypothesis linking brain to cognition. The actual decisions made by the participants are fed into the program, which then adjusts the model (such as those parameters that may be expected to vary according to the context) to provide a model that most closely fits the overall behaviour of the group. This best-fit model can then be used to estimate the response of the reward system at different points in the game for an individual, and estimating the reward signal in this way provided a better prediction of whether a learner would recall new information than just the points available for a correct answer (Howard-Jones, Demetriou, Bogaca, Yoo & Leonards, 2011). If, in such ways, concepts from cognitive neuroscience can provide a scientifically valid basis for understanding human behaviour in learning games, then these concepts may have considerable value in developing educational software. They also have potential in developing pedagogy for whole-class gaming managed by the teacher. Through further action research, concepts from neuroscience and psychology have provided the basis for developing a pedagogy for teaching with immersive gaming. It has also led to the development of software (free to all teachers) that allows the teaching of almost any topic through whole-class gaming (see Figure 3). This software was launched in September 2012 and at the time of writing (May 2013) it has been used 20 000 times across 20 countries.

Apart from demonstrating the potential of neuroscience to stimulate and develop new educational understanding, this set of studies again emphasises the need for interdisciplinary research across natural and social science perspectives, and for research that employs a radical mixture of methods adapted to support the interrelation of these perspectives. The ways in which these studies have supported each other are multiple and diverse. The initial bridging study was quasi-experimental but was adapted to collect evidence of how students talked about their feelings when experiencing chance-based uncertainty in their learning. This qualitative experiential evidence prompted the second study focusing on student discourse. The second study involved the qualitative interpretation of dialogue but applied neuropsychological concepts in developing the analysis. Observations in the classroom have also raised questions

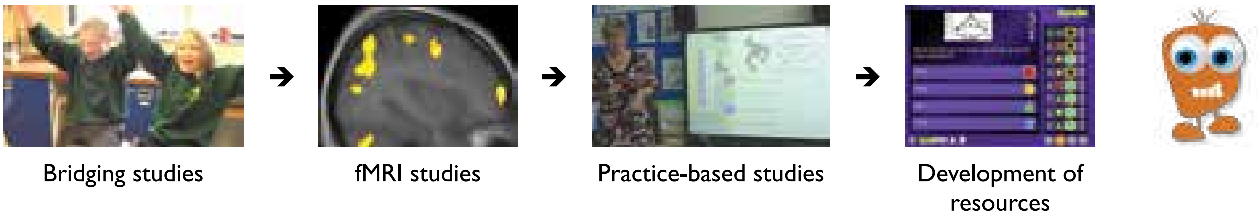


Figure 3 The NEnet investigation of learning games has involved bridging studies in the classroom and neuro-imaging studies to understand the competitive brain, leading to the development of free software that a teacher can use to teach any topic as a whole-class game ('Team Play' on http://www.zondle.com)

about the types of reward signal generated during competition, which is a key feature of most educational games but with little existing neuroscientific research to provide insight. These research questions have now been considered in a neurocomputational study of competitive learning using brain imaging (Howard-Jones, Bogacz, Yoo, Leonards & Demetriou, 2010), and the models developed in this study are forming the basis of further classroom investigations into learning games.

This is just a selection of the ways in which the natural and social sciences can meet and support each other in neuroeducational research that attempts to develop both a scientific and an educational understanding of learning. The active involvement of educational and neuroscientific experts in collaborative research has also highlighted the need for care when communicating messages and findings from integrating perspectives. This is essential for avoiding the types of neuro-myths that introduced this article. For example, words such as 'motivation', 'reward', 'attention' and even 'learning' appear to have different meanings within neuroscience and education. A neuroeducational research approach, based on dialogue and co-construction of concepts, can help identify these issues and develop appropriate messages that are, as far as possible, inoculated against misinterpretation and misunderstanding. Although it is a longer journey than attempting to apply neuroscience directly in the classroom, it is suggested here that the most effective pathways to success in neuroeducation are likely to resemble the trajectory shown in Figure 4.

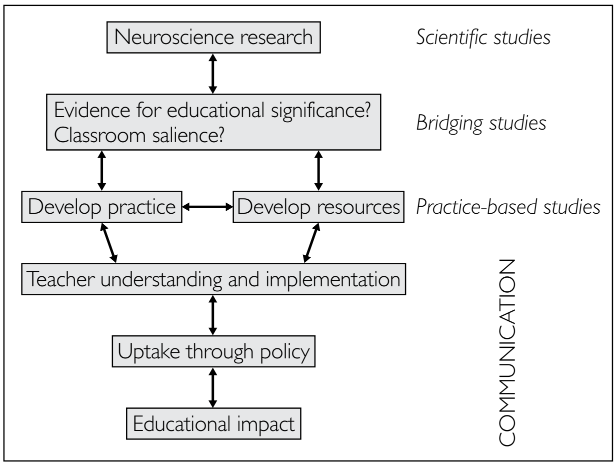


Figure 4 Effective pathways to success in neuroeducation

The dialogue between neuroscience and education is still in its infancy but already suggests the need for a new field of enquiry that is both scientifically and educationally grounded. Psychological understanding of learning will be crucial in linking neural processes to learning achieved in a classroom. Educational thinking also needs to be involved at every stage, from developing tractable and useful questions to executing the research and communicating its findings. Innovation will be required in developing the methodology to embrace both natural and social science perspectives in this way. If it can rise to these challenges, neuroeducational research may enrich both education and the sciences of mind and brain.

RESOURCES

The major online resources are http://www.neuroeducational.net, the website of the Neuroeducational Research Network, coordinated from the Graduate School of Education, University of Bristol, and http://www.zondle.com, the website of Zondle. Zondle have helped apply the insights from Neuroscience and NEnet research to develop 'Team Play' – an application that allows a teacher to deliver any topic using whole-class gaming approach. Teachers have already developed 12 000 topics that can be used with Team Play (and these are available to all). The site is available in many different languages.

The major print resource is P. A. Howard-Jones (2010), *Introducing neuroeducational research: Neuroscience, education and the brain from contexts to practice*, Abingdon, UK: Routledge.

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