Brain Waves Module 2:

Neuroscience: implications for education and lifelong learning

February 2011

EXCELLENCE IN SCIENCE

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Cover image: A map composed of data submitted to OpenStreetMap of people walking, driving and cycling around central London. The thicker the lines, the more people travelled that route, an appropriate metaphor for the way our brains develop networks of connected neurons through learning. Professor Eleanor Maguire and colleagues at UCL have advanced our understanding of how the brain changes in response to learning in adulthood. Maguire and colleagues showed that licensed taxi drivers, who spend years acquiring 'the Knowledge' of London's complex layout, have greater grey matter volume in a region of the brain known to be essential for memory and navigation. (Woollett K, Spiers HJ, & Maguire EA (2009). *Talent in the taxi: a model system for exploring expertise*. Phil Trans R Soc B 364(1522), 1407–1416.)

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RS Policy document 02/11
Issued: February 2011 DES2105

ISBN: 978-0-85403-880-0

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Brain Waves Module 2: Neuroscience: implications for education and lifelong learning

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Summary

Education is about enhancing learning, and neuroscience is about understanding the mental processes involved in learning. This common ground suggests a future in which educational practice can be transformed by science, just as medical practice was transformed by science about a century ago. In this report we consider some of the key insights from neuroscience that could eventually lead to such a transformation.

- Neuroscience research suggests that learning outcomes are not solely determined by the environment. Biological factors play an important role in accounting for differences in learning ability between individuals.
- By considering biological factors, research has advanced the understanding of specific learning difficulties, such as dyslexia and dyscalculia. Likewise, neuroscience is uncovering why certain types of learning are more rewarding than others.
- The brain changes constantly as a result of learning, and remains 'plastic' throughout life. Neuroscience has shown that learning a skill changes the brain and that these changes revert when practice of the skill ceases. Hence 'use it or lose it' is an important principle for lifelong learning.
- Resilience, our adaptive response to stress and adversity, can be built up through education with lifelong effects into old age.
- Both acquisition of knowledge and mastery of self-control benefit future learning. Thus, neuroscience has a key role in investigating means of boosting brain power.
- Some insights from neuroscience are relevant for the development and use of adaptive digital technologies. These technologies have the potential to create more learning opportunities inside and outside the classroom, and throughout life. This is exciting given the knock-on effects this could have on wellbeing, health, employment and the economy.
- There is great public interest in neuroscience, yet accessible high quality information is scarce. We urge caution in the rush to apply so-called brain-based methods, many of which do not yet have a sound basis in science. There are inspiring developments in basic science although practical applications are still some way off.
- The emerging field of educational neuroscience presents opportunities as well as challenges for education. It provides means to develop a common language and bridge the gulf between educators, psychologists and neuroscientists.

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This report has been reviewed by an independent panel of experts and also approved by the Council of the Royal Society. The Royal Society gratefully acknowledges the contribution of the reviewers. The review panel were not asked to endorse the conclusions or recommendations of the report, nor did they see the final draft of the report before its release.

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Acknowledgements

We would like to thank all those consulted during the course of this study, including the eminent neuroscientists and policy officials who helped during the scoping of the work as well as those who attended the Royal Society's stakeholder discussion *'Education: what's the brain got to do with it?'* held in partnership with the Wellcome Trust. See Appendices 1 and 2 for details.

1 Introduction

Education is the wellspring of our health, wealth and happiness. It allows human beings to transcend the physical limits of biological evolution. We know that education works through experiences that are dependent on processes in the brain, and yet we still understand far too little about these processes. Neuroscience studies have begun to shed light on the mental processes involved in learning. In this report we explore the extent to which these new scientific insights can inform our approach to education.

The rapid progress in research in neuroscience is producing new insights that have the potential to help us understand teaching and learning in new ways. Education is far more than learning facts and skills such as reading. It is not confined to the school years, but plays an important role throughout the lifespan and helps individuals cope with adversity. Flexibility through learning enables people of any age to adapt to challenges of economic upheaval, ill health, and ageing. The new field of 'educational neuroscience', sometimes called 'neuroeducation', investigates some of the basic processes involved in learning to become literate and numerate; but beyond this it also explores 'learning to learn', cognitive control and flexibility, motivation as well as social and emotional experience. With the effective engagement of all learners as well as teachers, parents and policy makers, the impact of this emerging discipline could be highly beneficial.

Education affects the wellbeing of individuals and has economic benefits.[1] The economic and social cost of an education system that does not facilitate learning for all and learning throughout life is high.[2–4] There is accumulating scientific knowledge that could benefit all groups of learners: children, young people, adults and older people. Small experimental steps have already been taken, from the application of particular reward programmes in learning,[5] to cognitive training of the elderly in care homes in order to reduce their need for medication.[6] In this report we touch on the widespread desire to enhance cognitive abilities, for instance through smart drugs. However, we propose that education is the most powerful and successful cognitive enhancer of all.

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1 OECD (2010). *The High Cost of Low Educational Performance*, *The Long-run Economic Impact of Improving Educational Outcomes.* OECD: Paris.

2 Accurate figures are hard to find, *see Science and Technology Committee for a discussion, Evidence Check 1: Early literacy interventions*. www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/44/4405.htm#n28Oct Accessed 15 December 2010.

3 Every Child a Chance Trust estimate poor literacy to cost the UK £2.5 billion, Every Child a Chance (2009) Trust. *The long term costs of literacy difficulties, 2nd edition.* Every Child a Chance: London.

4 KPMG Foundation estimate poor numeracy to cost England £2.4 billion per year, KPMG Foundation (2006), *The long-term effects of literacy difficulties.* KPMG: London.

5 Howard-Jones PA & Demetriou S (2009). *Uncertainty and engagement with learning games*. Instructional Science **37**, 519–536.

6 Wolinsky FD, Mahncke H, & Kosinski M et al. (2010). *The ACTIVE cognitive training trial and predicted medical expenditures.* BMC Health Services Research **Volume: 9**, 109.

It is inspiring to see public enthusiasm for the application of neuroscience to education. This suggests that it will transfer readily into the support structures it needs in schools, further education, higher education and beyond. At the same time, enthusiasm is often accompanied by poor access to new knowledge and misconceptions of neuroscience findings.[7,8] We believe that a constructive balance between enthusiasm and scepticism, combined with better knowledge exchange between scientists and practitioners can help resolve this problem.

This report focuses on the implications for education of understanding neuroscience combined with cognitive psychology. The aims of this report are to:

- present important developments in neuroscience that have the potential to contribute to education;
- discuss the challenges that exist for educators and neuroscientists; and
- present policy recommendations to facilitate the translation of new developments into practice.

This is the second of four modules in the Royal Society Brain Waves series on neuroscience and society.

7 Blakemore SJ & Frith U (2005). The Learning Brain: Lessons for Education. Oxford: Blackwell.
8 Goswami U (2004). Neuroscience and Education. British Journal of Educational Psychology 1–14.

2 Insights and opportunities

Neuroscience is the empirical study of the brain and connected nervous system. The brain is the organ that enables us to adapt to our environment—in essence, to learn. Neuroscience is shedding light on the influence of our genetic make-up on learning over our life span, in addition to environmental factors. This enables us to identify key indicators for educational outcomes, and provides a scientific basis for evaluating different teaching approaches. In this section, we set out some of the key insights and opportunities stemming from findings from neuroscience.

2.1 Both nature and nurture affect the learning brain

Individuals differ greatly in their response to education, and both genes and the environment contribute to these differences. Work with identical twins, who have the same genetic make-up, has shown that they are more similar in, for instance, personality[9], reading[10] and mathematical ability[11], than non-identical twins, who differ in their genetic make-up. (Please see Figure 1 for an example of how genetic similarity maps onto brain structure). While it is widely agreed that individual differences can have a genetic basis, genetic influences on brain development and brain function are not yet well understood.

For example, while genetic predispositions can partially explain differences in reading ability, there is no single gene that makes an individual a good or poor reader. Instead, there are multiple genes, the individual effects of which are small.[12] Furthermore genes can be turned on and off by environmental factors such as diet,[13,14] exposure to toxins[15] and social interactions.[16–18] And in terms of neurobiology (the biology of the brain and central nervous system), our current knowledge does not allow us to use

9 Eaves L, Heath A, Martin N, Maes H, Neale M, & Kendler K, et al (1999). *Comparing the biological and cultural inheritance of personality and social attitudes in the Virginia 30,000 study of twins and their relatives.* Twin Research **2(2)**, 62–80.

10 Harlaar N, Spinath FM, Dale PS, & Plomin R (2005). *Genetic influences on early word recognition abilities and disabilities: a study of 7-year-old twins.* Journal of Child Psychology and Psychiatry **46**, 373–384.

11 Kovas Y, Haworth CMA, Petrill SA, & Plomin R (2007). *Mathematical ability of 10-year-old boys and girls: Genetic and environmental etiology of typical and low performance*. Journal of Learning Disabilities **40(6)**, 554–567.

12 Bishop DVM (2009). *Genes, cognition and communication: insights from neurodevelopmental disorders. The Year in Cognitive Neuroscience*: Annals of the New York Academy of Sciences Mar; **1156**, 1–18.

13 Jaenisch R & Bird A (2003). *Epigenetic regulation of gene expression: how the genome integrates intrinsic and environmental signals*. Nature Genetics **33**, 245–254.

14 Waterland RA & Jirtle RL (2003). *Transposable Elements: Targets for Early Nutritional Effects on Epigenetic Gene Regulation—Molecular and Cellular Biology* **23(15)**, 5293–5300.

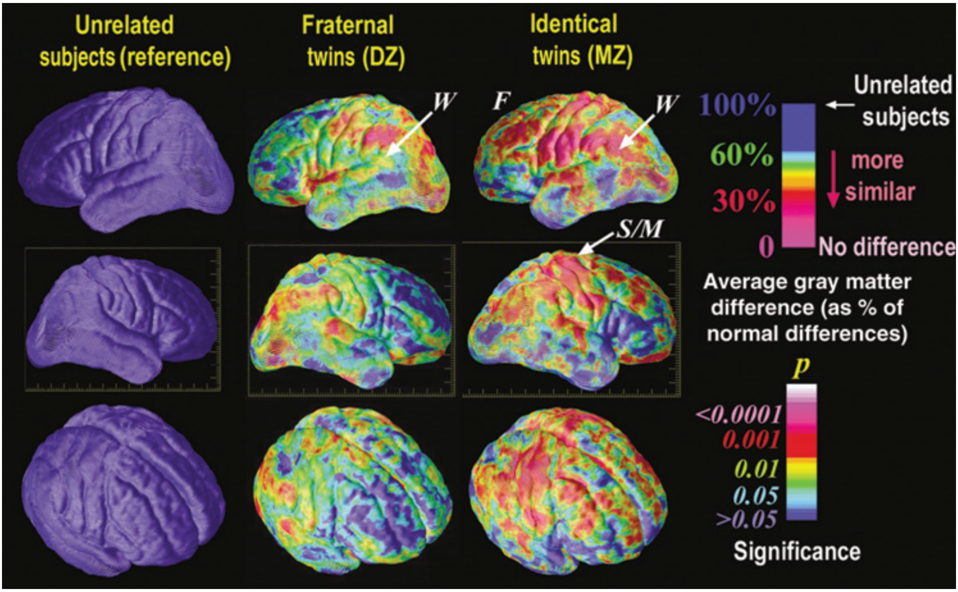
15 Dolinoy DC & Jirtle RL (2008). *Environmental epigenomics in human health and disease.* Environmental and Molecular Mutagenesis **49(1)**, 4–8.

16 Rutter M, Dunn J, Plomin R, Simonoff E, Pickles A, Maughan B, Ormel J, Meyer J, & Eaves L (1997) – *Integrating nature and nurture: Implications of person-environment correlations and interactions for developmental psychopathology*. Development and Psychopathology **9(2)**, 335–364.

17 Van Praag H, Kempermann G, & Gage FH (2000). Neural consequences of environmental enrichment – Nature Reviews Neuroscience **1**, 191–198.

18 Champagne FA & Curley JP (2005) *How social experiences influence the brain*. Current Opinion in Neurobiology **15(6)**, 704–709.

Figure 1. Genetic continuum of similarity in brain structure. Differences in the quantity of gray matter at each region of cortex were computed for identical and fraternal twins, averaged and compared with the average differences that would be found between pairs of randomly selected, unrelated individuals (blue, left). Color-coded maps show the percentage reduction in intra-pair variance for each cortical region. Fraternal twins exhibit only 30% of the normal inter-subject differences (red, middle), and these affinities are largely restricted to perisylvian language and spatial association cortices. Genetically identical twins display only 10–30% of normal differences (red and pink) in a large anatomical band spanning frontal (F), sensorimotor (S/M) and Wernicke's (W) language cortices, suggesting strong genetic control of brain structure in these regions, but not others (blue; the significance of these effects is shown on the same color scale). Reprinted by permission from Macmillan Publishers Ltd: Nature Neuroscience (Thompson, P. M., Cannon, T. D., Narr, K. L., Van Erp, T., Poutanen, V., Huttunen, M., et al. (2001). Genetic influences on brain structure. Nature Neuroscience, **4***, 1253–1258), copyright (2001).*



measurement of activity in a brain region to tell whether an individual is a good or poor reader. There is enormous variation between individuals, and brain-behaviour relationships are complex.[19]

Genetic make-up alone does not shape a person's learning ability; genetic predisposition interacts with environmental influences at every level. Human learning abilities vary, in the same way that human

19 Giedd JN & Rapoport JL (2010). *Structural MRI of pediatric brain development: what have we learned and where are we going?* Neuron **67**(**5**), 728–734.

height and blood pressure vary. And just as for height and blood pressure, while there are some rare genetic conditions that lead to extreme abnormality, most variations in learning capacity are caused by multiple genetic and environmental influences, each of which may have a small impact. Neuroscience has the potential to help us understand the genetic predispositions as manifest in the brain of each individual, and how these predispositions (nature) can be built on through education and upbringing (nurture).[20]

2.2 The brain is plastic

The brain is constantly changing and everything we do changes our brain. These changes can be short lived or longer lasting. When we sleep, walk, talk, observe, introspect, interact, attend, and learn, neurons fire. The brain has extraordinary adaptability, sometimes referred to as 'neuroplasticity'. This is due to the process by which connections between neurons are strengthened when they are simultaneously activated; often summarised as, 'neurons that fire together wire together'.[21] The effect is known as experience-dependent plasticity and is present throughout life.[22]

Neuroplasticity allows the brain to continuously take account of the environment. It also allows the brain to store the results of learning in the form of memories. In this way, the brain can prepare for future events based on experience. On the other hand, habit learning, which is very fast and durable, can be counterproductive for individuals and difficult to overcome, as for example in addiction.[23,24]

Key findings based on neuroplasticity include the following:

- Changes in the brain's structure and connectivity suggest there are sensitive periods in brain development extending beyond childhood into adolescence.[25–30] Plasticity tends to decrease with age and this is particularly evident when we consider learning of a second language: mastery of speech sounds and grammatical structure is generally better in those introduced to a second

20 Taylor J, Roehrig AD, Hensler BS, Connor CM, & Schatschneider C (2010). *Teacher quality moderates the genetic effects on early reading.* Science **328**, 512–514.
21 Hebb D (1949). *The Organization of Behavior*. Wiley, New York.
22 Lovden M, Backman L, Lindenberger U, Schaefer S & Schmiedek F (2010). *A theoretical framework for the study of adult cognitive plasticity*, Psychol Bull **136(4)**, 659–76.
23 Hogarth L, Chase HW, & Baess K (2010). *Impaired goal-directed behavioural control in human impulsivity*. Q J Exp Psychol **10**,1–12.
24 de Wit S & Dickinson A (2009). *Associative theories of goal-directed behaviour: a case for animal-human translational models*. Psychol Res **73(4)**, 463–76.
25 Thomas M & Knowland V (2009). *Sensitive Periods in Brain Development – Implications for Education Policy.* European Psychiatric Review **2(1)**, 17–20.
26 Knudsen EI (2004). *Sensitive Periods in the Development of the Brain and Behavior*. Journal of Cognitive Neuroscience **16(8)**, 1412–1425.
27 Johnson MH (2001). *Functional brain development in humans* Nature Reviews Neuroscience **2**, 475–483.
28 Andresen SL (2003). *Trajectories of brain development: point of vulnerability or window of opportunity?* Neuroscience & Biobehavioral Reviews **27(1–2)**, 3–18.
29 Lenroot RK & Giedd JN (2006). *Brain development in children and adolescents: insights from anatomical magnetic resonance imaging*. Neuroscience & Biobehavioral Reviews **30(6)**, 718–729.

language before puberty compared with later in life.[31,32] During adolescence, certain parts of the brain undergo more change than others. The areas of the brain undergoing most change control skills and abilities such as self awareness, internal control, perspective taking and responses to emotions such as guilt and embarrasement.[33]

- The overall pattern of neural development appears to be very similar between genders, but the pace of brain maturation appears to differ, with boys on average reaching full maturation at a slightly later age than girls.[34] At first glance this suggests that boys and girls might do better if educated separately, especially around puberty and early adolescence, when the gender difference in brain development is greatest. However, there are many factors that influence brain development, and gender is only one example of an individual difference that might influence learning and development.

- Dynamic changes to brain connectivity continue in later life. The wiring of the brain changes progressively during development for a surprisingly long time. For example, the connections in the frontal part of the brain involved in impulse control and other 'executive' functions are pruned progressively and adaptively during adolescence and beyond. Even after these developmental changes, activity-dependent plasticity is evident throughout life: For example, licensed London taxi drivers, who spend years acquiring 'the Knowledge' of London's complex layout, have greater grey matter volume in a region of the brain known to be essential for memory and navigation (see Figure 2).[35]

- Just as athletes need to train their muscles, there are many skills where training needs to be continued to maintain brain changes. The phrase 'use it or lose it!' is very apt. In the taxi driver example above, a reversal in brain changes was found following retirement, when taxi drivers were no longer employing their spatial memory and navigation skills.[36] Changes in the adult brain following the acquisition of specific skills has also

30 Shaw P, Kabanai NJ, Lerch JP, Eckstrand K, Lenroot R, Gogtay N, Greenstein D, Clasen L, Evans A, Rapoport JL, Giedd JN, & Wise SP (2008). *Neurodevelopment Trajectories of the Human Cerebral Cortex*. Journal of Neuroscience 28(14), 3586–3594.

31 Hernandez AE & Li P (2007). *Age of acquisition: Its neural and computational mechanisms*. Psychological Bulletin 133(4), 638–650.

32 Johnson JS & Newport EL (1989). *Critical period effects in second language learning: the influence of maturational state on the acquisition of English as a second language.* Cognitive Psychology 1989 21(1), 60–99.

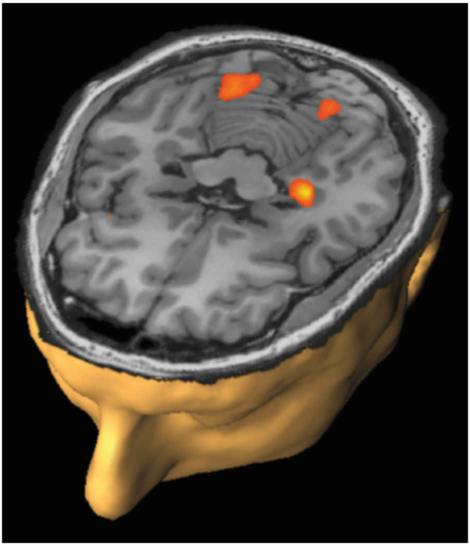
33 Blakemore SJ (2008). *The social brain in adolescence*. Nature Reviews Neuroscience 9(4), 267–277.

34 Giedd JN & Rapoport JL (2010). *Structural MRI of pediatric brain development: what have we learned and where are we going?* Neuron 67(5), 728–734.

35 Woollett K, Spiers HJ, & Maguire EA (2009). *Talent in the taxi: a model system for exploring expertise.* Phil Trans R Soc B 364(1522), 1407–1416.

36 See section 2.7 below for more in relation to cognitive decline.

Figure 2. The hippocampus of a licensed London taxi driver is highly active when navigating around the city, and its volume increases the more spatial knowledge and experience they acquire.[39]



been shown for music,[37] juggling[38] and dance.[40] This illustrates what we mean by experience-dependent plasticity. The genetic specification of our brains only partly determines what we know and how we behave; much depends on environmental factors that determine what we experience. Education is prominent among these factors.

- There are limits to neuroplasticity as well as individual differences. Not all learning appears to be subject to sensitive periods, and unlearning habits is remarkably hard. There appear to be limits on how internal predispositions and external stimulation can affect learning. For instance, only half of those who attempt to qualify as London cabbies actually succeed. We also know that after brain injury some functions seem to be more amenable to rehabilitation than others, and some cannot be relearned at all.[41] However many different factors play a role in recovery and compensation, and both pharmacological treatments and training regimes are being studied as potential means for extending plasticity into adulthood.[42]

2.3 The brain's response to reward is influenced by expectations and uncertainty

Neuroscience research has revealed that the brain's response to reward[43] is influenced by many different factors

37 Gaser C & Schlaug G (2003). *Brain Structures Differ between Musicians and Non-Musicians.* Journal of Neuroscience **23(27)**, 9240–9245.
38 Draganski B, Gaser C, Busch V, Schuierer G, Bogdahn U, & May A (2004). *Neuroplasticity: Changes in grey matter induced by training.* Nature **427**, 311–312.
39 Woollett K, Spiers HJ, & Maguire EA (2009). Talent in the taxi: a model system for exploring expertise. *Philosophical Transactions of the Royal Society, London: Series B* **364**: 1407–1416.
40 Hanggi J, Koeneke S, Bezzola L, & Jancke L (2009). *Structural neuroplasticity in the sensorimotor network of professional female ballet dancers.* Human Brain Mapping **31(8)**, 1196–1206.
41 Corrigan PW & Yudofsky SC (1996). *Cognitive Rehabilitation for Neuropsychiatric Disorders*. American Psychiatric Press, Inc: Washington, DC.
42 Bavelier D, Levi DM, Li RW, Dan Y, & Hensch TK (2010). *Removing brakes on adult brain plasticity: from molecular to behavioral interventions.* Journal of Neuroscience **30**, 14964–14971.
43 Here we use a very broad definition of reward, which includes but is not restricted to 'primary rewards' (rewards that satisfy physiological needs such as the need for food) and 'secondary rewards (rewards based on values, such as social admiration).

including context[44] and individual differences.[45] Neuroscientists have studied the relationship between reward and learning in the context of reinforcement learning, in which we learn to attribute values to simple actions. In this type of learning, the individual's reward system responds to prediction error, which is the difference between the outcome we expect from an action and the outcome we actually get. It is this response of the reward system that allows us to learn which action has the most valuable outcome. Some neuroscientists think that just reducing prediction errors by making better predictions about outcomes can itself be rewarding. The brain's response to prediction error also supports other types of learning that are of great potential interest to educators, such as the ability to recall information.[46] Research also demonstrates that the degree of uncertainty about the reward one might receive is an important contributor to the magnitude of the neural response it generates[47] (and implicitly the reward's operational value). This challenges educational notions of a simple relationship between reward and motivation in school, and may suggest new ways to use reward more effectively in education to support learning.[48]

2.4 The brain has mechanisms for self-regulation

Together with findings from cognitive psychology, neuroscience is beginning to shed light on self-regulation and self control, that is, the inhibition of impulsive behaviour.

Recent research has shown that the ability to inhibit inappropriate behaviour, for example, stopping oneself making a previously rewarded response, develops relatively slowly during childhood, but continues to improve during adolescence and early adulthood.[49] This is probably because the brain regions involved in inhibition, in particular the prefrontal cortex, continue to change both in terms of structure and function, during adolescence and into the twenties.[50] In addition, there are large individual differences in our ability to exert self-control, which persist throughout life. For example, by age three, some children are much better than others at resisting temptation, and the ability to resist temptation (delayed gratification) at this age has been found to be associated with higher education attainment in later

44 Nieuwenhuis S, Heslenfeld DJ, Alting von Geusau NJ, Mars RB, Holroyd CB, & Yeung N (2005). *Activity in human reward-sensitive brain areas is strongly context dependent.* Neuroimage **25**, 1302.

45 Krebs RM, Schott BH, & Duzel E (2009). *Personality Traits Are Differentially Associated with Patterns of Reward and Novelty Processing in the Human Substantia Nigra/Ventral Tegmental Area*. Biological Psychiatry **65**, 103.

46 Howard-Jones PA, Bogacz R, Demetriou S, Leonards U, & Yoo J (2009). In *British Psychological Society Annual Conference* (Brighton).

47 Fiorillo CD, Tobler PN, & Schultz W (2003). *Discrete Coding of Reward Probability and Uncertainty by Dopamine Neurons*. Science **299**, 1898.

48 Howard-Jones PA & Demetriou S (2009). Uncertainty and engagement with learning games. Instructional Science **37**, 519–536.

49 Blakemore SJ & Choudhury S (2006). *Development of the adolescent brain: implications for executive function and social cognition.* Journal of Child Psychology and Psychiatry **47**, 296–297.

50 Luna B & Sweeney JA (2004). *The Emergence of Collaborative Brain Function: fMRI Studies of the Development of Response Inhibition*. Annals of the New York Academy of Science **1021**, 296–309.

childhood and adolescence.[51] Research is under way to investigate to what extent cognitive training programmes can strengthen this ability.[52]

Understanding mechanisms underlying self-control might one day help to improve prospects for boosting this important life skill. In addition, it is important to learners and teachers who are dealing with lack of discipline or antisocial behaviour. Given that the self-reported ability to exert self-control has been found to be an important predictor of academic success,[53] understanding the neural basis of self-control and its shaping through appropriate methods would be valuable.

2.5 Education is a powerful form of cognitive enhancement

Cognitive enhancement usually refers to increased mental prowess, for instance, increased problem-solving ability or memory. Such enhancement is usually linked with the use of drugs or sophisticated technology. However, when compared with these means, education seems the most broadly and consistently successful cognitive enhancer of all.[54] Education provides, for instance, access to strategies for abstract thought, such as algebra or logic, which can be applied in solving a vast range of problems and can increase mental flexibility. Literacy and numeracy change the human brain,[55] but also enable human beings to perform feats that would not be possible without these cultural tools, including the achievements of science. The steady rise in IQ scores over the last decades is thought to be at least partially due to education.[56,57] Findings from neuroscience and cognitive enhancement include the following:

- Education can build up an individual's cognitive reserve and resilience, that is, their adaptive response to stressful and traumatic events and illness, including brain injury, mental disorder, and normal ageing. Cognitive reserve and resilience can be built up at any point during life. Research on cognitive reserve has found an inverse relationship between educational attainment and risk of dementia, which means that keeping the mind active slows cognitive decline and improves cognitive abilities in older adults.[58,59]

51 Mischel W, Shoda Y, & Rodriguez ML (1989). *Delay of gratification in children*. Science **244**, 933–938.
52 Sahakian BJ, Malloch G, & Kennard C (2010). *A UK strategy for mental health and wellbeing*. The Lancet **375**, 1854.
53 Duckworth A & Seligman M (2005). *Self-Discipline Outdoes IQ in Predicting Academic Performance of Adolescents.* Psychological Science **16(12)**, 939–944.
54 Bostrom N & Sandberg A (2009). *Cognitive Enhancement: methods, ethics, regulatory challenges*. Sci Eng Ethics **15(3)**, 311–41.
55 Dehaene S (2009). *Reading in the Brain*. Viking Penguin: London.
56 Flynn J (2007). *What is intelligence?: beyond the Flynn effect.* Cambridge University Press: New York
57 Blair C, Gamson D, Thorne S, & Baker D (2004). *Rising mean IQ: Cognitive demand of mathematics education for young children, population exposure to formal schooling, and the neurobiology of the prefrontal cortex.* Intelligence **33(1)**, 93–106.
58 Barnett JH & Sahakian BJ (2010). *Cognitive reserve and mental capital*. In Cooper GL, Field J, Goswami U, Jenkins R, & Sahakian BJ (Eds). *Mental capital and wellbeing*. Wiley-Blackwell: London.
59 Elliott R, Sahakian BJ, & Charney D (2010). *The neural basis of resilience*. In Cooper GL, Field J, Goswami U, Jenkins R, & Sahakian BJ (Eds). *Mental capital and wellbeing*. Wiley-Blackwell: London.

- Physical health, exercise, sleep and nutrition are crucial to physical and mental wellbeing and their effects on cognitive functions are mediated by the brain. For example, neuroscience research on sleep and sleep deprivation can explain some highly specific effects on memory and other mental functions.[60] Both physical and mental exercise are known to benefit older people, for example by acting as protective factors against, and reducing the symptomatic impact of dementia.[61–64]
- Pharmacological cognitive enhancers, sometimes referred to as 'smart drugs', such as Ritalin or Modafinil, are typically prescribed to counteract cognitive deficits in diagnosed conditions. But they are increasingly being used 'off-licence' in people with normal brain function,[65] along with many other over-the-counter drugs. These smart drugs have been used to overcome jet-lag, reduce the need for sleep, and boost motivation and concentration, by affecting the role of neurotransmitters in certain cognitive processes. Research is needed in order to establish the side effects of taking such drugs, their long term consequences and the risks involved. This research needs to take account also of the ethical issues that arise from questions like access and fairness.[66,67]

2.6 There are individual differences in learning ability with a basis in the brain

There is wide variation in learning ability; some individuals struggle to learn in all domains, whereas others have specific difficulties for instance, with language, literacy, numeracy or self control. There is ample evidence that these individuals are at increased risk of poor social adaptation and unemployment. The costs to society[68] are thus substantial and there is an urgent need to find educational approaches that will work.

Current work in neuroscience is directed toward identifying the brain basis of learning difficulties. As this research advances, prospects are raised for identification and diagnosis, and for designing interventions that are suitable

60 Dang-Vu TT, Schabus M, Desseilles M, Sterpenich V, Bonjean M, & Maquet P (2010). *Functional neuroimaging insights into the physiology of human sleep*. Sleep **33(12)**,1589–1603.

61 Orrell M & Sahakian B (1995). *Education and dementia*. British Medical Journal **310**, 951.

62 Wilson RS, Hebert LE, Scherr A, Barnes LL, Mendes de Leon CF, & Evans DA (2009). *Educational attainment and cognitive decline in old age.* Neurology **72**, 460–465.

63 Middleton LE, Mitniski A, Fallah N, Kirkland SA, & Rockwood K (2008). *Changes in cognition and mortality in relation to exercise in late life: A population based study*. PLoS One **3(9)**, e3124.

64 Stern Y, Gurland B, Tatemichi TK, Tang MX, Wilder D, & Mayeux R (1994). *Influence of education and occupation on the incidence of Alzheimer's Disease. JAMA* **271**, 1004.

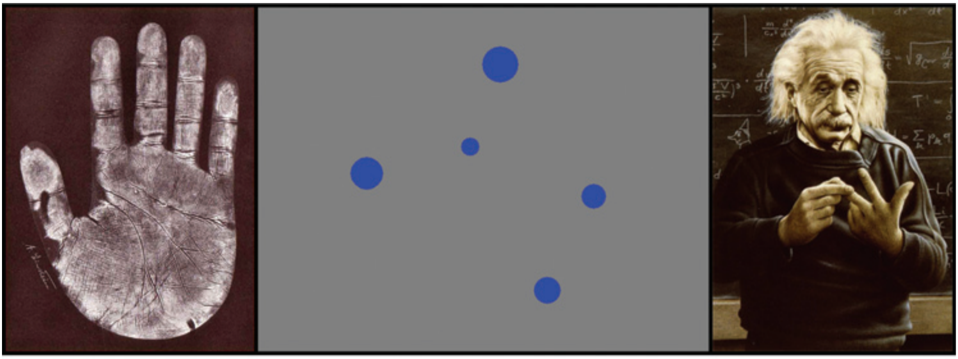
65 Sahakian BJ & Morein-Zamir S (2007). *Professor's little helper. Nature* **450**, 1157.

66 Maher B (2008). *Poll results: Look who's doping. Nature* **452**, 674.

67 See Brain Waves Module 1 Section 3.2 (neuropsychopharmacology), Text box 2, Section 4.3 (risks) and 4.3 (ethics) for broader discussion.

68 See for example Beddington, J, Cooper CL, Field J, Goswami U, Huppert FA, Jenkins R, et al (2008). *The mental wealth of nations*. Nature **455**, 1057–1060.

Figure 3. Making the link between sets and numbers. (1) Einstein's hand, (2) A display used in tests of numerical capacity, and (3) one way of mapping the set of dots to the set of fingers by counting. Dyscalculics are not good at estimating the number of objects in displays like (2), often have poor mental representations of their fingers, but continue to use them for calculation when other learners can calculate in their head.



(1) (2) (3)

for different ages and may overcome or circumvent the learning difficulties. Even for those with severe learning difficulties, improved understanding of specific cognitive and neurological correlates of disorder can be harnessed to make education more effective.[69]

Much neuroscientific research has focused on more specific learning difficulties, such as developmental dyslexia and developmental dyscalculia, where mastery of reading or maths pose unusual difficulties for the child. (Please see Figure 3 for an example). Research has identified underlying cognitive deficits which can be assessed by experimental tests, and may explain other difficulties that are often associated with poor attainment. There is less research directed at other problems.[70] Many children have specific problems understanding or producing spoken language (specific language impairment), poor motor skills (developmental co-ordination disorder or developmental dyspraxia) or marked symptoms of inattention, hyperactivity and impulsivity (attention deficit hyperactivity disorder or ADHD).

These conditions are not confined to childhood but can be lifelong. There is no 'biological' test at present; only behavioural tests are available.

69 Fidler DJ & Nadel L (2007). *Education and children with Down syndrome: Neuroscience, development, and intervention.* Mental Retardation and Developmental Disabilities Research Reviews **13(3)**, 262–271.

70 Bishop DVM (2010). *Which neurodevelopmental disorders get researched and why?* PLOS One **5(11)**, e15112.

Furthermore, there is no hard-and-fast dividing line between normality and abnormality: the diagnosis is made when an individual's difficulties are severe enough to interfere with everyday life and educational achievement. Many of those affected have more than one of these difficulties.[71]

Educational difficulties are common: a recent report found that in 2009 2.4 per cent of boys and 0.9 per cent of girls across all schools in England had statements of SEN (Special Educational Needs) and a further 23 per cent of boys and 14 per cent of girls were assessed as needing extra or different help from that provided as part of the school's usual curriculum (School Action or School Action Plus).[72]

Although research has shown there are brain correlates, or markers, for learning difficulties, these markers are subtle and complex. As yet it is not possible to predict or assess an individual's specific learning disability from a brain scan.[73] This is because even within a diagnostic category, such as developmental dyslexia, there is substantial anatomical variation from one individual to another. Improvements in the diagnosis of learning disabilities through technical advances in the variety of neuroimaging methods and through the refinement of cognitive tests can be expected in the next decade. In a similar vein, while there is strong evidence that genetic factors are implicated in specific learning disabilities,[74] one can seldom identify a single gene as responsible, because multiple genes are involved and their impact depends on the environment.[75]

Furthermore, even when a genetic risk or neurological basis for a learning disability can be identified, this does not mean the individual is unteachable; rather, it means that it is necessary to identify the specific barriers to learning for that person, and find alternative ways.

The study of dyslexia, using a combination of behavioural and neuroimaging methods, illustrates that it is possible to identify neuro-cognitive barriers to learning and to make suggestions for appropriate teaching methods. Other learning difficulties can benefit from the same kind of approach to uncovering underlying neural systems. Results from functional neuroimaging studies show that dyslexic children and adults have abnormal patterns of activation in areas of the brain involved in language and

71 Bishop D & Rutter M (2008). *Neurodevelopmental disorders: conceptual approaches*. In M Rutter, D Bishop, D Pine, S Scott, J Stevenson, E Taylor, & A Thapar (Eds). *Rutter's Child and Adolescent Psychiatry* (pp. 32–41). Blackwell: Oxford.

72 Taken from Department for Children, Schools and Families Statistical First Release 15/2008. 25 June 2008. Available online at http://www.education.gov.uk/rsgateway/DB/STA/t000851/index.shtml. Accessed 8 December 2010.

73 Giedd JN & Rapoport JL (2010). *Structural MRI of pediatric brain development: what have we learned and where are we going?* Neuron **67(5)**, 728–734.

74 Willcutt EG, Pennington BF, Duncan L, Smith SD, Keenan JM, & Wadsworth S, et al (2010). Understanding the complex etiologies of developmental disorders: Behavioral and molecular genetic approaches. Journal of Developmental and Behavioral Pediatrics **31(7)**, 533–544.

75 For a discussion see www.deevybee.blogspot.com/2010/09/genes-for-optimism-dyslexia-and-obesity.html. Accessed 15 December 2010.

reading.[76,77] The application of knowledge gained from these studies to improve intervention is still at an early stage,[78,79] but educationally relevant randomised controlled trials of improving literacy are already available.[80]

The study of ADHD reminds us that the way the brain works is affected by levels of neurotransmitters that influence connectivity between brain regions and levels of excitation and inhibition. Neuroimaging studies combined with pharmaceutical intervention can give insights into underlying neural mechanisms such as behaviour control in ADHD, where one symptom is difficulty in impulse control.[81] A future goal is to devise cognitive training approaches that influence the same neural circuitry.

There is a widespread belief in some circles that ADHD is a convenient label used to explain away bad behaviour, with corresponding concern that medication is being used to control what is essentially normal behaviour.[82] Neuroscience provides concrete evidence of biological differences between children with ADHD and others, but nevertheless, we need to be alert to the possibility of over-diagnosis, since current diagnostic criteria are based solely on behavioural assessments. During school years and until adolescence, behaviour that might indicate specific problems with impulse control changes rapidly, in line with brain development. Thus, immaturity, which might be due to a child being born late in the school year, can be mistaken for ADHD.[83] On the other hand, under-diagnosis may happen in the context of uncritical acceptance of individual differences and reluctance to make any distinction between normal and abnormal behaviour. With refined methods of behavioural testing, informed by findings from neuroscience and genetics, it should become possible to improve on the current approach to diagnosis for all neuro-developmental disorders.[84]

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76 Maurer U, Brem S, Bucher K, Kranz F, Benz R, Steinhausen H-C, & Brandeis D (2007). *Impaired tuning of a fast occipito-temporal response for print in dyslexic children learning to read.* Brain **130**, 3200–3210.

77 Activity in left posterior superior temporal cortex is reduced (Turkeltaub PE, Gareau L, Flowers DL, Zeffiro TA, & Eden GF (2003). *Development of neural mechanisms for reading*. Nature Neuroscience **6(6)**, 767–773.).

78 Dehaene S (2009). *Reading in the Brain*. Viking Penguin: London.

79 Goswami U & Szucs D (2010). *Educational neuroscience: Developmental mechanisms: Towards a conceptual framework.* Neuroimage, Setp 7, Epub ahead of print.

80 Bowyer-Crane C, Snowling MJ, Duff FJ, Fieldsend E, Carroll JM, Miles J, et al (2008). *Improving early language and literacy skills: Differential effects of an oral language versus a phonology with reading intervention.* Journal of Child Psychology and Psychiatry, **49**, 422–432.

81 Chamberlain SR & Sahakian BJ (2006). *Attention deficit hyperactivity disorder has serious and immediate implications.* Education Journal **94**, 35–37.

82 See Brain Waves Module 1 Section 4.2 (risks) for a broader discussion.

83 Elder TE (2010). *The importance of relative standards in ADHD diagnoses: Evidence based on exact birth dates*. Journal of Health Economics **29(5)**, 641–656.

84 Morton J (2004). *Understanding Developmental Disorders; A Causal Modelling Approach*. Blackwells: Oxford.

2.7 Neuroscience informs adaptive learning technology

Neuroscientific findings can often identify a specific locus for a particular kind of learning difficulty. They may not determine the exact form an intervention should take, but they may well suggest the nature of the concept or skill to be targeted, and the kind of cognitive activity that needs to be strengthened. However, even where successful teaching approaches have been developed for learners who cannot keep up with the mainstream classes, widespread implementation may fail because there are too few specially trained teachers, and the level of frequent and individual attention that many learners need is unaffordable. Learning technologies have the potential to play a complementary role to that of the teacher in assisting the rehearsal of targeted learning activities. The experimental designs that give rise to neuroscientific insights can often be adapted to support remediation and transferred to technology-based platforms, such as laptops or mobile phones.

For example, research has identified poor grasp of 'number sense'—having an intuitive sense of, say, fiveness—as an underlying cause of arithmetical learning disability (dyscalculia).[85,86] Computer games have been designed to give learners practice in understanding numbers that adapt to the learner's current skill-level; for example, by introducing larger numbers as the learner gets better; or by matching dot arrays with digits or number words. Adaptive game-like programs make use of the individual's natural reward system (see Section 2.3): they show the difference between the outcome the learner expects from an action and the outcome they actually observe. This helps them to learn which action has the most valuable outcome. Adaptive programmes emulate a teacher who constantly adapts to current learner understanding. Thus they enable far more practice than is often possible through one-to-one teaching.[87]

Although we must treat claims about brain-training programmes[88–90] and the use of neuroscience in diagnosis with the utmost caution, there is evidence to suggest that:

- With practice, high quality targeted training can improve performance

85 Von Aster MG & Shalev RS (2007). *Number development and developmental dyscalculia*. Developmental Medicine & Child Neurology **49(11)**, 868–873.

86 Piazza M, Facoetti A, Trussardi AN, Berteletti I, Conte S, Lucangeli D, Dehaene S, & Zorzi M (2010). *Developmental trajectory of number acuity reveals a severe impairment in developmental dyscalculia*. Cognition **116(1)**, 33–41.

87 Butterworth B & Laurillard D (2010). *Low numeracy and dyscalculia: Identification and intervention*. ZDM Mathematics Education, Special issue on Cognitive neuroscience and mathematics learning **42(6)**, 527–539.

88 Owen AM, Hampshire A, Grahn JA, Stenton R, Dajani S, Burns AS, Howard RJ, & Ballard CG (2010). *Putting brain training to the test*. Nature **465(7299)**, 775–8. But see Klingberg 2010 [91].

89 Hyatt KJ & Brain Gym R (2007). *Building stronger brains or wishful thinking?* Remedial and special education **28(2)** 117–124.

90 Strong GK, Torgerson CJ, Torgerson D, & Hulme C (2010). *A systematic meta-analytic review of evidence for the effectiveness of the 'Fast ForWord' language intervention program.* Journal of Child Psychology and Psychiatry, Oct 15, 1469–7610.

on specific tasks. A key question is whether training effects transfer to other tasks. In most studies, training effects seem highly task-specific.[91] Nevertheless, there is currently considerable interest in a working memory training programme for children that is thought to lead to improvements in reasoning ability and self-regulation.[92,93] This work is particularly impressive because efficacy has been demonstrated in randomised controlled trials.

- Digital technologies can be developed to support individualised self-paced learning and highly specialised practice in a game-like way (see Figure 4). Interactive games of this kind use a teacher-pupil model to adapt the task to the learner's needs, and a task model to provide meaningful feedback on their actions. This means interactive technologies can provide personalised help on a daily basis[94] in a way that is difficult to achieve in a demanding classroom environment.
- Further developments in neuroscience technology might provide effective support for people with significant sensory or physical deficits. Research

Figure 4. Digital technologies are highly versatile, and can support individualised, self paced learning for people of all ages, inside or outside of formal education. Image courtesy of David Pegon.

91 Owen AM et al. (2010). See Ref 87.
92 Klingberg T (2010). *Training and plasticity of working memory*. Trends In Cognitive Sciences **14**, 317.
93 McNab F, Varrone A, Farde L, Jucaite A, Bystritsky P, Forssberg H, & Klingberg T (2009). *Changes in Cortical Dopamine D1 Receptor Binding Associated with Cognitive Training.* Science **323**, 800–802.
94 See for example Wilson A, Dehaene S, Pinel P, Revkin SK, Cohen L, & Cohen D (2006). *Principles underlying the design of 'The Number Race', an adaptive computer game for remediation of dyscalculia.* Behavioural and Brain Functions **2**,19.

into brain-computer interfaces brings new hope to those individuals who cannot control a computer, keyboard, or robotic arm in the normal way: in the future they may be able to use their own brain signals to perform the necessary actions.[95]

- Adaptive learning technologies that target remote learning can also be used to provide daily support for adult learners and individuals beyond retirement age, who for whatever reason are not attending classes on a regular basis. Digital media based on learning targets identified by neuroscience, for example, practicing links between speech sounds and letters in the case of reading difficulties, offer a more private learning context, but can still be linked to teachers online. Teachers would provide expert feedback on progress based on, but going beyond, the feedback from the adaptive software. Importantly lifelong learning and cognitive training have wider benefits for health and wellbeing.[96–98]

95 See Brain Waves Module 1 Section 3.3 for an extended discussion on brain-machine interfaces.

96 Government Office for Science (2008). *Foresight Project on Mental Capital and Wellbeing*. Government Office for Science: London.

97 Medical Research Council (2010). *Review of Mental Health Research Report of the Strategic Group*, Medical Research Council: London.

98 Sahakian BJ, Malloch G, & Kennard C (2010). *A UK strategy for mental health and wellbeing*. The Lancet **375**, 1854–55.

3 Challenges

Scientific proposals for educational neuroscience may seem alien or even unhelpful. This is due, in part to major cultural and vocabulary differences between the scientific research and education communities. Let us start by considering some common ground. Both perspectives recognise that if individuals do not master basic skills in language, literacy or numeracy, then there are serious challenges to educational attainment, vocational and social prospects. Both perspectives also recognise that education allows us to develop better ways of helping all individuals find a fulfilling and productive place in society. Despite these common aims, neuroscience is often accused of 'medicalising' the problems of people with educational difficulties.

3.1 The charges of reductionism and determinism

Critics of neuroscience fear that it represents:

- a reductionist view that overemphasises the role of the brain at the expense of a holistic understanding of cultural life based on interpretation and empathy;
- a determinist view that our neurological inheritance sets us on a path that is unchangeable.[99]

However, a neuroscience perspective recognises that each person constitutes an intricate system operating at neural, cognitive, and social levels, with multiple interactions taking place between processes and levels.[100] Neuroscience is a key component of this system and is therefore a key contributor to enriching explanations of human thought and behaviour. Furthermore, it is a mistake to regard biological predispositions as deterministic; their impact is probabilistic and context-dependent. The important point, as section 2 describes, is that there are educational difficulties that have a biological basis, and cannot be attributed solely to parents', teachers' or society's expectations. If in these cases the biological risk factors are not taken into account, important opportunities to optimise learning will be missed.

3.2 The inappropriate exploitation of neuroscience

A web search using Google with the keywords 'Learning', 'Teaching', and 'Brain' indicates that there is a huge demand for applications of brain science to education.[101] Thus despite philosophical reservations, there is considerable enthusiasm for neuroscience and its applications. This can, however, lead to problems.

99 See Brain Waves Module 1 Section 3.4 and Text Box 5 for a broader discussion.

100 Rosenzweig MR, Breedlove SM, & Leiman AL (2001). *Biological Psychology: An Introduction to Behavioral, Cognitive, and Clinical Neuroscience.* Sinauer Associates Inc: Sunderland, MA.

101 See also Pickering SJ & Howard-Jones PA (2007). *Educators' views on the role of neuroscience in education: Findings from a study of UK and international perspectives*. Mind, Brain and Education **1**, 109–113, for a survey.

For example, commercial interests have been quick to respond to the demand of the enthusiasts and promote their credibility with testimonials of reportedly trustworthy individuals. There is already a glut of books, games, training courses, and nutritional supplements, all claiming to improve learning and to be backed by science. This is problematic because the sheer volume of information from a range of sources makes it difficult to identify what is independent, accurate and authoritative. At worst, this industry creates 'neuro-myths' that can damage the credibility and impact of authentic research.[102,103]

3.3 Building a common language

'Knowledge needs to go in both directions' is a quote that typifies the sentiments expressed by neuroscience, policy and teaching communities, and is taken from a recent Royal Society and Wellcome Trust stakeholder discussion 'Education: What's the brain got to do with it?'[104]

If educational neuroscience is to develop into an effective new discipline, and make a significant impact on the quality of learning for all learners, we need a long-term dialogue between neuroscientists and a wide range of other researchers and professionals from a variety of backgrounds.[105]

To address the need for engagement that was highlighted at the Royal Society and Wellcome Trust stakeholder meeting, the Working Group believes a professionally managed web-based forum would be helpful. Such a forum would help bring together practitioners and scientists in a continuing dialogue. This would go a long way towards counteracting misconceptions on either side. For example, neuroscientists could provide evaluations of commercially offered programmes and current research findings. Educators could provide evaluations of teaching programmes; and representatives from different disciplines could provide critical reviews. A flexible tool, such as this type of forum, would serve multiple purposes, for example, increasing general knowledge about brain science for teachers and learners. This would also instil the scepticism that is needed to evaluate novel educational programmes.

A knowledge-sharing mechanism is clearly a worthwhile aim. However, aligning the needs and interests of different professions presents a substantial challenge.[106] There are significant differences in assumptions, theories, phenomena of interest, and vocabulary.[107]

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102 See Geake J (2008). *Neuromyths in Education*, Educational Research **50(2)**,123–133 and Waterhouse L (2006) *Multiple intelligences, the Mozart effect, and emotional intelligence: A critical review*. Educational Psychologist **41(4)**, 207–225 for example reviews.

103 See Weisberg DS et al. (2008) for more discussion, Weisberg DS, Keil FC, Goodstein J, Rawson E, & Gray JR (2008). *The Seductive Allure of Neuroscience Explanations.* Journal of Cognitive Neuroscience **20(3)**, 470–477.

104 See Appendix 2 for details.

105 See Brain Waves Module 1 Section 4.4 (governance) for a broader discussion.

106 Kalra P & O'Keefe JK (2010). *Making disciplinary perspectives explicit and other best practices for interdisciplinary work in educational neuroscience*. Front. Neurosci. Conference Abstract: EARLI SIG22 - Neuroscience and Education.

107 Royal Society and Wellcome Trust stakeholder meeting, Education: What's the brain got to do with it? 7 September 2010, see Appendix 2.

4 Recommendations

Growing understanding of the neurological basis of learning could help most individuals to become fulfilled and productive members of society who can respond with resilience to changing circumstances in their lives. This applies not only to children of school age who are getting to grips with literacy and numeracy, but also to adolescents whose career choices lie before them, and adults contributing to the economy through their use of skills in the workforce. It also applies to the elderly who wish to maintain existing skills, and learn new ones to help counteract the effects of decline. In this section we set out key findings and recommendations from the emerging field of educational neuroscience which might inform education policy across all ages.

4.1 Strengthening the science base for education

Neuroscience research aims to characterise the mechanisms of learning and the sources of individual differences in learning ability. It is therefore a tool for science-based education policy, which can help assess the performance and impact of different educational approaches. In addition, neuroscience can provide knowledge of how education offers wider policy benefits, in health, employment and wellbeing.[108,109]

Recommendation 1

Neuroscience should be used as a tool in educational policy.

Neuroscience evidence should inform the assessment of different education policy options and their impacts where available and relevant. Neuroscience evidence should also be considered in diverse policy areas such as health and employment.

Stronger links *within* the research community and *between* researchers and the education system (schools, further education, higher education and institutes for lifelong learning) are needed in order to improve understanding of the implications of neuroscience for education. Department for Education, Department for Business Innovation and Skills and Devolved Administration equivalents as well as research funders, such as the Economic and Social Research Council and Wellcome Trust, should provide incentives to support mechanisms to develop cross-sector links.

4.2 Informing teacher training and continued professional development

Findings from neuroscience that characterise different learning processes can support and enhance teachers' own experiences of how individuals learn. These findings can be used to inform alternative teaching approaches for

108 Beddington J, Cooper GL, Field J, Goswami U, Huppert FA, Jenkins R, Jones HS, Kirkwood TBL, Sahakian BJ, & Thomas SM (2008). *The mental wealth of nations.* Nature **455**, 1057–1060.

109 Sahakian BJ, Malloch G, & Kennard C (2010). *A UK strategy for mental health and wellbeing*. The Lancet **375**, 1854.

learners of different abilities. However, at present neuroscience rarely features as part of initial teacher training courses or as part of continued professional development.[110,111]

Recommendation 2

Training and continued professional development should include a component of neuroscience relevant to educational issues, in particular, but not restricted to, Special Educational Needs.

Teacher training providers for Special Education Needs across all ages should consider including a focus on the neurobiological underpinnings of learning difficulties such as dyslexia, dyscalculia and ADHD. This training should be extended to teachers for all ages.

4.3 Informing adaptive technologies for learning and cognitive training

New educational technologies provide opportunities for personalised learning that our education system cannot otherwise afford. They can also open up learning opportunities outside the classroom and hence improve access to those currently excluded from education in adulthood and in later life. Insights from neuroscience, for example how the brain benefits from exercise, and how the brain understands numeracy, can help inform the design of educational technologies. To this end, links between neuroscientists and the digital technologies industry could be strengthened.

Recommendation 3

Neuroscience should inform adaptive learning technology.

Neuroscience can make valuable contributions to the development of adaptive technologies for learning. The Technology Strategy Board should promote knowledge exchange and collaboration between basic researchers, front-line practitioners and the private sector in order to inform and critically evaluate the impact and development of new technologies.

4.4 Building bridges and increasing knowledge of neuroscience

A growing corpus of neuroscience evidence already exists which is relevant for education. However, for some, this evidence can be difficult to access and evaluate. Findings from neuroscience are all too easily misinterpreted and applied out of context. A continued dialogue among the research base (that includes neuroscientists, cognitive psychologists

110 Royal Society and Wellcome Trust stakeholder meeting, Education: What's the brain got to do with it? 7 September 2010.
111 See Royal Society State of the Nation Report on 5–14 Science and Mathematics Education (2010), which calls for more specialist training for primary science and maths teachers in particular.

and social scientists) as well as frontline teachers across all ages and the policy community is required. Good work in building bridges has already started.[112]

Recommendation 4

Knowledge exchange should be increased.

A knowledge exchange network is required to bridge disciplines, this should include a professionally monitored web forum to permit regular feedback between practitioners and scientists and to ensure that research is critically discussed, evaluated and effectively applied. High quality information about neuroscience on a web forum could also be made available to the general public, for example by the BBC and/or Open University. Members of the public will benefit from learning about the changes that are going on in their own brains and how this can affect their own learning.

112 See the Economic and Social Sciences Research Council Teaching and Learning Research Programme (TLRP) Commentaries available at www.tlrp.org/pub/commentaries.html. Accessed 15 December 2010.

Appendix 1 Consultation list

- Adrian Alsop, Head of Research, Economic and Social Sciences Research Council
- Libby Archer, Age UK
- Bahador Bahrami, PhD student, Visual Cognition Group, University College London
- Adam Bailey, Performance Service Agreement, Older People & Ageing Society, Department for Work and Pensions
- Derek Bell, Director of Education, Wellcome Trust. Professor
- Stephen Breslin, Chief Executive, Future Lab
- Tony Brown, Director Escalate, Education Research Centre under the Higher Education Authority
- Neil Burgess, Deputy Director, Institute of Cognitive Neuroscience, University College London
- Professor Cary Cooper, Chair of Scientific Coordination Team on Foresight project, Pro-Vice Chancellor and Distinguished Professor of Organisational Psychology and Health, Lancaster University
- Alan Cowey, Emeritus Professor of Physiological Psychology, Oxford Centre for Functional Magnetic Resonance Imaging of the Brain, Department of Clinical Neurology, University of Oxford
- Ron Dahl, Professor, Community Health & Human Development and Joint Medical Program, University of California, Berkeley
- James Dancy, Government Office for Science, Department for Business, Innovation and Skills
- Peter Dayan, Director, Gatsby Computational Neuroscience Unit, University College London
- Stan Dehaene, CNRS
- Tony Dickinson, Cambridge
- Ray Dolan, Director, Wellcome Trust Centre for Neuroimaging, University College London
- Ellie Donnett, Department of Pharmacology, University of Oxford
- Jon Driver, Professor, Institute of Cognitive Neuroscience, University College London
- John Duncan, Professor, MRC Cognition and Brain Sciences Unit, University of Cambridge
- Sue Dutton, Lifelong Learning UK
- Tony Gardner-Medwin, Professor Emeritus, Department of Physiology, University College London
- Michael Gazzaniga, Director, SAGE Center for Study of the Mind, University of California, Santa Barbara
- Peter van Gelder, Westminster Forum Projects
- Brenda Gourley, National Institute of Adult Continuing Education
- Baroness Susan Greenfield of Ot Moor

- Jennifer Groff, Fulbright Scholar, Research Innovation in Learning and Education, Future Lab
- Patrick Haggard, Group Leader, Institute of Cognitive Neuroscience, University College London
- Antonia Hamilton, Lab for Social Cognition, University of Nottingham
- Karen Hancock, Chief Economist, Department Children, Families and Schools
- Heidi Johansen-Berg, Wellcome Senior Research Fellow, Nuffield Department of Clinical Neurosciences, Oxford Centre for Functional Magnetic Resonance Imaging of the Brain
- Eric Kandel, Nobel Prize Winner and Founding Member of the Department of Neuroscience at Columbia
- Annette Karmiloff-Smith, Research Fellow, Developmental Neurocognition Lab, Centre for Brain and Cognitive Development, Birkbeck College
- Mark Langdon, Life Long Learning, Department for Business, Innovation and Skills
- Liz Lawson, Team Leader, Informal Adult Learning, Department for Business, Innovation and Skills
- Rose Luckin, Professor of Learner Centred Design, London Knowledge Lab, Institute of Education, University of London
- Dr Carol Lupton, Senior Principal Research Officer, Department of Health
- Trevor Mutton, PGCE Course Leader, Department of Education, University of Oxford
- Baroness Estelle Morris of Yardley
- Jacquie Nunn, Director of Training Development, Teaching and Development Agency
- Jon Parke, Foresight Department for Business, Innovation and Skills
- Isobel Pastor, Government Office for Science, Department for Business, Innovation and Skills
- Tim Pearson, Technology Strategy Board
- Baroness Pauline Perry of Southwark
- Professor Chris Philipson, Keele, Universities UK
- Daniel Pine, Chief Investigator, Section on Development and Cognitive Development, Affect Neuroscience, National Institute of Mental Health
- Michael Posner, Professor Emeritus, Institute of Cognitive and Decision Sciences, University of Oregon, New York Sackler Institute
- Cathy Price, Wellcome Trust Centre for Neuroimaging, University College London
- VS Ramachandran, Director, Center for Brain and Cognition, University of California, San Diego
- Geraint Rees, Wellcome Trust Senior Clinical Fellow and Professor of Cognitive Neurology, University College London

- Mike Reiss, Institute for Education
- Katherine Richardson, Senior Officer for Science, Maths and ICT Pedagogy, TeachFirst
- Ros Ridley, Researcher, Cambridge
- Charles Ritchie, Higher Education Research and Analysis, Department for Business, Innovation and Skills
- Giacomo Rizzolatti, Director, Department of Neuroscience, University of Parma
- Matthew Rushworth, Professor, Oxford Centre for Functional Magnetic Resonance Imaging of the Brain
- Ayse Saygin, Assistant Professor, Department of Cognitive Science, University of California, San Diego
- Wolfram Schultz, Wellcome Principal Research Fellow, Department of Physiology, Development and Neuroscience, University of Cambridge
- Sophie Scott, Professor of Speech Communication, Institute of Cognitive Neuroscience, University College London
- Dr Bob Stephenson, Lower Master of Eton College
- Lauren Stewart, Goldsmiths
- David Teeman, Senior Research Officer National Foundation for Education Research
- Hugh Tollyfield, Deputy Director, deputy director Hugh Tollyfield, Post 16 Curriculum Improvement Team, Department for Business, Innovation and Skills
- Leslie Ungerleider, Senior Investigator, Section on Neurocircuitry, Laboratory of Brain & Cognition, National Institute of Mental Health
- William Waldegrave, Provost of Eton College
- Professor Shearer West, Director of Research at AHRC
- Carole Willis, Chief Scientific Adviser, Department Children, Families and Schools
- Dr Stephen Witt, Research Strategy Team, Strategic Analysis, Research and Policy Impact Group (SARPI), Department for Education
- Jonathan Yewdall, Head Further Education team, Department for Business, Innovation and Skills

Appendix 2 Stakeholder Discussion Education: What's the brain got to do with it?

Programme and attendees of the Royal Society and Wellcome Trust stakeholder meeting, Education: What's the brain got to do with it? 7 September 2010

1. Letter from Uta Frith, Chair of the *Brain Waves* Working Group on Neuroscience: Implications for Education and Lifelong Learning
2. Programme
3. *Brain Waves*: project summary
4. Biographies of Working Group members
5. List of invited participants
6. Discussion questions submitted by participants
7. Ten example claims from neuroscience that might impact on education

Added after the discussion

8. Preliminary analysis of the Twitter feed

1. Letter from Uta Frith, Chair of the Brain Waves Working Group on Neuroscience: implications for education and lifelong learning

Dear participant,

Education: what's the brain got to do with it?

I am delighted to welcome you to this discussion.

In recent years there has been growing interest, both public and professional, at the interface of neuroscience end education, with scientific findings and approaches being successfully and unsuccessfully adapted to schools and other learning environments. Today's discussion will feed into one part of a Royal Society study that will investigate developments in neuroscience and their implications for society. In the module, 'Neuroscience, Education and Lifelong Learning' we aim to:

- develop a framework to better communicate advances in neuroscience research to policy makers and the teaching community
- facilitate a dialogue between neuroscientists, policy makers and the teaching community
- identify current and future impacts of neuroscience research, including wider societal/ethical perspectives and to describe these in terms of policy and teaching outcomes.

The central activity of the event is a number of parallel round table discussions. On each table scientists, teachers, policy makers, and others will make up something like a book club. Here we aim to have informal discussions where everyone can contribute their own perspective. We don't have books to discuss, but instead we would like to focus on a number of provocative claims at the interface of neuroscience and education. For example, can an understanding of how the brain processes speech and numbers help us improve literacy and numeracy? Or, can an understanding of how the brain continues to develop during adulthood and older age help us improve skills in the workforce and the welfare of older people? Science can provide all sorts of evidence, but it remains to be seen whether this evidence is of any use to the central question of education and life-long learning.

Each of you has a valuable contribution to make to these discussions, bringing your outlook, experience and expertise. These insights will feed into a report that we are writing that we hope will act as a catalyst for further engagement between the different communities. It will be ready early in 2011 and will be made publicly available. I would like to thank you for joining us today, and for your contribution to this debate.

In addition, I would like to take this opportunity to thank the Wellcome Trust, who are supporting this event. 'Understanding the Brain' is one of their five major challenges for the next ten years, and we're delighted to be joined by such a significant partner in UK science today.

I hope you enjoy this afternoon and wish you a stimulating discussion.

Uta Frith

Chair of the Royal Society Brain Waves Working Group on Neuroscience Implications for Education and Lifelong Learning

2. Programme

Education: what's the brain got to do with it?

A stakeholder meeting Chaired by Baroness Estelle Morris, Tuesday 7 September 2010, 4.30pm-7.00pm followed by a reception

Location: Wellcome Trust Lecture Hall, The Royal Society, 6-9 Carlton House Terrace, London SW1Y 5AG

Number of participants: ~100, an equal mix of neuroscientists, teachers, policy officials and other interested stakeholders

4.00pm–4.30pm	**Registration (30 minutes)**
4.30pm–5.05pm	**Part 1—Setting the scene (35 minutes)**
4.30pm–4.35pm	Welcome from Professor Uta Frith FBA, FRS FMedSci, Chair of the Royal Society *Brain Waves* Working Group on Neuroscience, Education and Lifelong Learning
4.35pm–4.45pm	Evidence in Education policy, Baroness Estelle Morris (Chair)
4.45pm–4.55pm	Introduction to Neuroeducation, Professor Barbara Sahakian FMedSci, Cambridge University

4.55pm–5.00pm	Discussion format, Daniel Glaser, Wellcome Trust
5.00pm–5.50pm	**Part 2—Series of ten interactive round table discussions (50 minutes)**
5.00pm–5.50pm	Discussion structured around specific questions, although participants will also be free to discuss other topics too. The discussions will be logged live via Twitter.
5.50pm–6.05pm	Break for tea, coffee (15 minutes)
6.05pm–6.55pm	**Part 3—Open floor discussion (50 minutes)**

This will kick-off with two-minute inflections from the following:

Rapporteur 1	Professor Sarah-Jayne Blakemore, Neuroscientist, UCL
Rapporteur 2	Professor Michael Reiss, Assistant Director, Institute of Education
Rapporteur 3	John Crossland, Educational Consultant
Rapporteur 4	Bob Stephenson, Deputy Head Master of Eton College
Rapporteur 5	Liz Lawson, Team leader, Informal Adult Learning, BIS
Rapporteur 6	Richard Bartholomew, Chief Research Officer, Children and Families Directorate, DfE

6.15pm–6.30pm	**David Willetts, Minister of State for Universities and Science (5 minutes)**
6.55pm–7.00pm	**Closing remarks from Baroness Estelle Morris (5 minutes)**
7.00pm	**Reception**
7.15pm	Speech from Wellcome Trust

3. Brain Waves: project summary

Science Policy Centre

The Royal Society has launched a new project, **Brain Waves**, which will investigate developments in neuroscience and their implications for society. The project will be led by a Steering Group Chaired by **Professor Colin Blakemore FRS**.

Increasing understanding of the brain and associated advances in technologies to study the brain will enable improved treatment of neurodegenerative diseases, such as Parkinson's and Alzheimer's, and mental illnesses, including depression and schizophrenia. But these advances will also increase our insights into normal human behaviour and mental wellbeing, as well as giving the possibility of other enhancement, manipulation, and degradation of brain function.

These developments are likely to provide significant benefits for society, and they will also raise major social and ethical issues due to wide ranging applications. Particular areas of technology development include: functional neuroimaging; neuropharmacology and drug delivery; brain stimulation technologies; genomics and molecular genetics techniques for understanding brain function; and brain-machine interfaces.

Brain research is likely to have implications for a diverse range of public policy areas such as health, education, law, and security. More broadly progress in neuroscience is going to raise questions about personality, identity, responsibility, and liberty.

Brain Waves will explore the potential and the limitations of neuroscience insights for policymaking, as well as the benefits and the risks posed by applications of neuroscience and neurotechnologies.

The project will comprise four modules running in sequence until the end of 2011, with each producing a corresponding report:

- Module 1: Neuroscience, society and ploicy
- Module 2: Neuroscience, education and lifelong learning
- Module 3: Neuroscience, conflict and security
- Module 4: Neuroscience, responsibility and the law

For more information on the project, please see http://royalsociety.org/brainwaves/

4. Biographies of Working Group members

Brain Waves Module 2 Working Group on Neuroscience, Education and Lifelong Learning:

Professor Uta Frith FRS FBA FMedSci (Chair)

Uta Frith is Emeritus Professor at University College London where she was a founding member of the UCL Institute of Cognitive Neuroscience. In addition to this, she is also a research foundation Professor at the University of Aarhus. Her research interests include autism and Asperger syndrome; developmental dyslexia; social cognition and the impact of neuroscience on teaching and learning. Uta has written many books on autism and Asperger syndrome and co-authored the book *The Learning Brain* with Sarah-Jayne Blakemore.

Professor Dorothy Bishop FBA FMedSci

Dorothy Bishop is a Professor of Developmental Neuropsychology and Wellcome Principal Research Fellow at the Department of Experimental Psychology, University of Oxford. Her main areas of research are developmental language disorders, laterality and behaviour genetics. Dorothy has co-edited *Rutter's Child and Adolescent Psychiatry*.

Professor Colin Blakemore FRS FMedSci

Colin Blakemore is a Professor of neuroscience at Oxford University. He also holds Professorships at the University of Warwick and the Duke University—National University of Singapore Graduate

Medical School, where he is Chairman of Singapore's Neuroscience Research Partnership. Colin's research has been concerned with many aspects of vision, the early development of the brain and plasticity of the cerebral cortex. He has previously been chief executive of the Medical Research Council, and is currently chair of the General Advisory Committee on Science at the Food Standards Agency, in addition to being a commissioner of the UK Drug Policy Commission.

Professor Sarah-Jayne Blakemore

Sarah-Jayne Blakemore is a Royal Society University Research Fellow and Reader in Cognitive Neuroscience at University College London and. She is leader of the Developmental Cognitive Neuroscience Group at the Institute of Cognitive Neuroscience. Her research focuses on social cognition in adolescence and in autism spectrum disorders. Sarah-Jayne co-authored the book The Learning Brain, and is Co-Editor of Developmental Cognitive Neuroscience.

Professor Brian Butterworth FBA

Brian Butterworth is Professor of Cognitive Neuropsychology at University College London. Brian's research focuses on the development of mathematical abilities and how the brain processes numerical information. His group are also trying to develop methods for helping people who have difficulty with arithmetic, including those with congenital learning difficulties (dyscalculia). Other interests include neural network models of reading and arithmetic; in addition to reading and acquired dyslexia in English, Japanese and Chinese.

Professor Usha Goswami

Usha Goswami is a Professor of Education and Director at the Centre for Neuroscience in Education, University of Cambridge. Her research interests include cognitive development, reading development, dyslexia, spelling development, reasoning by analogy and neuroscience in education. Usha is a fast track editor of Developmental Science, and is on the editorial boards of the Journal of Child Psychology and Psychiatry, and Cognitive Development. She authored the *Learning difficulties: Future Challenges* module of the Foresight—Mental Capital and Wellbeing project.

Doctor Paul Howard-Jones

Paul Howard-Jones is a Senior Lecturer in Education at the Graduate School of Education, University of Bristol. His areas of research are in neuroscience and education: using our knowledge of the mind and brain to improve teaching and learning, game-based learning and creativity. Paul is coordinator of the Centre for Psychology and Learning in Context. Paul authored *Introducing Neuroeducational Research* (2010, Routledge) on how research can be undertaken at the interface of neuroscience and education.

Professor Diana Laurillard

Diana Laurillard is a Professor of Learning with Digital Technologies at the London Knowledge Lab, Institute of Education. Her research interests include developing an interactive learning design tool to support teachers moving to blended learning. As well as working with special education needs teachers to investigate the design of software interventions, for learners with dyscalculia and low numeracy. Previous to this Diana was head of the e-Learning strategy unit at the Department for Education and Skills.

Professor Eleanor Maguire

Eleanor Maguire is a Professor of Cognitive Neuroscience at the Wellcome Trust Centre for Neuroimaging, Institute of Neurology, University College London. Her research focuses on internal representation of large-scale space and our personal experiences within it, and to determine how both types of memory can be understood within a unified cognitive-neuroanatomical framework, that supports our integrated sense of who and where we are.

Professor Barbara Sahakian FMedSci

Barbara Sahakian is a Professor of Clinical Neuropsychology at the Department of Psychiatry, University of Cambridge School of Clinical Medicine. Her research is aimed at understanding the neural basis of cognitive, emotional and behavioural dysfunction. She also has an interest in pharmacogenomics and neuroethics resulting from recent studies of ecstasy use and cognitive enhancers. Barbara is a member of the Neurosciences and Mental Health Board at the MRC, and was part of the science co-ordination team for the Foresight—Mental Capital and Wellbeing project.

Annette Smith FInstP

Annette Smith is Chief Executive of the Association for Science Education which is the largest subject teaching association—the membership comprises teachers in all phases, teacher educators, advisors and inspectors and technicians and educational researchers.

Her first degree was in Physics from the University of Liverpool and she subsequently gained a PGCE and a Masters in Science Education. Annette has wide experience of the world of science education, with teaching experience in adult and further education as well as in secondary school science. She has been a lecturer in primary science education, an LEA laboratory technician and worked in industry in environmental health physics and safety. Recently, she held the role of President of the European Science Events Association (EUSCEA) and she is a Fellow of the Institute of Physics.

5. List of invited participants

Bahador Bahrami, PhD student, Visual Cognition Group, University College London

Hannah Baker, Project Manager, Education Policy Development, Wellcome Trust

John Barnbrook, Headteacher, Chepstow Comprehensive School

Richard Bartholomew, Chief Research Officer, Children and Families Directorate, Department for Education

Derek Bell, Head of Education, Wellcome Trust

Mike Bell, Teacher, Hinchingbrooke School

Neil Bluer, Acting Head of Science, Beardmore Technology College

Fidelma Boyd, Deputy Head Teaching and Learning, St Angela's Ursuline School

Alena Buyx, Assistant Director, Nuffield Council on Bioethics

Sarah Caddick, Principal Neuroscience Advisor to Lord Sainsbury, Gatsby Foundation

Sandy Callacher, Head of Community Science, Sydenham School

Ewen Callaway, Biomedical and Life Sciences Reporter, New Scientist

Bernadette Carelse, Educational Psychologist, The Learning Trust

Helen Casey, Executive Director, Faculty of Policy and Society, National Research and Development Centre for Adult Literacy and Numeracy

Bette Chambers, Director, Institute for Effective Education, University of York

Richard Churches, Principal Consultant for Learning and Teaching Consultancy, Centre for British Teaching Education Trust

Ross Cooper, Director and Head of Division - Dyslexia, Literacy and Learning Styles, LLU + , London South Bank University

John Crossland, General, Director, John Crossland Consultancy

James Dancy, Policy, Head of Health and Biotechnology Team, Government Office for Science, Department for Business, Innovation and Skills

Shirley Davison, Chairman, First Taste

Peter Dayan, Director, Gatsby Computational Neuroscience Unit, University College London

Hannah Devlin, Science Editor, The Times

Justin Dillon, Head of the Science and Technology Group, King's College London

Jeremy Dudman-Jones, Assistant Head Teacher, Greenford High School

Marie-Claude Dupuis, Advisory Committee on Mathematics Education (ACME) Officer, Royal Society

Jenny Edington, Headteacher, Water Mill Primary School

Mark Ellis, Teacher, Starks Field Primary School

Jane Emerson, Director, Emerson House

Yi Feng, Researcher, Faculty of Education, Cambridge University

Rod Flower FRS, Professor of Biochemical Pharmacology at the William Harvey Research Institute, St Barts and the London School of Medicine and Dentistry

Abigail Gibson, Senior Policy Analyst, UK Commission for Employment and Skills

Daniel Glaser, Head of Special Projects, Wellcome Trust

Brenda Gourley, Board Member, National Institute for Adult Continuing Education (NIACE)

Chris Green, Chair, Learning Skills Foundation

Dr Nick Green, Head of Projects, Royal Society

Sunjai Gupta, Deputy Director of Public Health Strategy & Social Marketing, Department of Health

Partrick Haggard, Group Leader, Institute of Cognitive Neuroscience, University College London

Linda Hargreaves, Reader in the Psychology of Education, Faculty of Education, Cambridge University

Laura Harper, Research Officer—Medicine, Society, and History Division, Wellcome Trust

Anne Helme, Assistant Education Manager, Royal Society

Annabel Huxley, Science Communications Consultant

Varsha Jagadesham, Research Officer, Nuffield Council on Bioethics

Ann Jeffcott, Research Development Manager, Economic and Social Research Council

Neil Ingram, Senior Lecturer in Science Education, University of Bristol

Ian Jones, Research, Royal Society Shuttleworth Research Fellow, University of Nottingham

Nicola Kane, Press Officer, Royal Society

Annette Karmiloff-Smith, Research Fellow, Developmental Neurocognition Lab, Centre for Brain and Cognitive Development, Birkbeck College

Paul Kelley, Headteacher, Monkeaton School

Carole Kenrick, Teacher, Teach First

Kieron Kirkland, Researcher, Future Lab

Vanessa Lacey, Head of Educational Support, Oundle School

John Landeryou, Director, Learning, Quality and Systems Directorate, Department for Business, Innovation and Skills

Christine Lawson, Psychologist, Child and Adolescent Mental Health Service

Liz Lawson, Lead for Informal Adult and Community Learning Department for Business, Innovation and Skills

Penny Lewis, Lecturer, University of Manchester

Rose Luckin, Professor of Learner Centred Design, London Knowledge Lab

Catherine Luckin, Policy Officer, Academy Of Medical Sciences

Peter McLoughlan, Teacher, Beardwood Humanities College

Sarah Mee, Policy Adviser, Royal Society,

Karen Mills, Headteacher, Lagenhoe Community Primary School

Baroness Estelle Morris of Yardley, House of Lords

John Morton, Institute of Cognitive Neuroscience, University College London

Isobel Pastor, Policy Advisory to Government Chief Scientific Advisor, Government Office for Science,

Baroness Pauline Perry of Southwark, Policy, House of Lords

Cathy Price, Wellcome Trust Centre for Neuroimaging at the Institute of Neurology, University College London

Sue Ramsden, Researcher, University College London

Geraint Rees, Wellcome Trust Senior Clinical Fellow and Professor of Cognitive Neurology at University College London and Director of the Institute of Cognitive Neuroscience, University College London

Michael Reiss, Associate Director and Professor of Science Education at the Institute of Education, University of London

David Reynolds, Professor of Education, Plymouth University

Daniel Sandford Smith, Director of Programmes at Gatsby Technical Educational Projects, Gatsby Foundation

Tom Schuller, Director, Longview

Sophie Scott, Professor of Speech Communication, Institute of Cognitive Neuroscience, University College London

Jonathan Sharples, Policy, Manager of Partnerships, Institute for Effective Education, University of York

Caroline Shott, Founder, Learning Skills Foundation

Tom Simpson, Operations Manager of the Higher Education Academy—Psychology Network, Higher Education Agency

Stephanie Sinclair, Project Manager, Education Policy Development, Wellcome Trust

Libby Steele, Head of Education, Royal Society

Bob Stephenson, Deputy Headteacher, Eton College

Juliet Strang, Headteacher, Villiers School

Ruth Talbot, Head of Early Learning and Care, Department for Education

Nigel Thomas, Director of Education, Gatsby Foundation

Ian Thornton, Policy Adviser, Royal Society

Andrew Tolmie, Head of Department of Psychology and Human Development, Institute of Education

Andrea Walker Patrick, Director, TOPIC (Tutoring Older People in Care) project, First Taste

Peter Wallis, Management Consultant

Vincent Walsh, Professor of Human Brain Research, Institute of Cognitive Neuroscience and Department of Psychology, University College London

Zoe Webster, Lead Technologist, Technology Strategy Board

Rupert Wegerif, Researcher, University of Exeter

Graham Welch, Chair of Music Education, Institute of Education

Joanna West, Early Learning and Care Team, Department for Education

Shearer West, Director of Research, Arts and Humanities Research Council

Karen Whitby, Research Manager, Centre for British Teaching Education Trust

Ro Wickramasinghe, Policy Adviser, Royal Society

Right Honourable David Willetts MP, Minister for Universities and Science

John Williams, Head of Neuroscience & Mental Health and Head of Clinical Activities, Wellcome Trust

Alan Wilson, Professor of Urban and Regional Systems in the Centre for Advanced Spatial Analysis at University College London and is Chair of the Arts and Humanities Research Council.

Peter Wright, Principal Scientific Adviser, Department for Work and Pensions

Emily Yeomans, Education Research Officer, Wellcome Trust

Chris Young, former Intern, Royal Society

Rapela Zaman, Senior Policy Adviser, Royal Society

6. Discussion questions submitted by attendees

1. What are the translational barriers to bringing neuroscience into current educational practice?

2. Do we need a new/differently trained kind of educator to practise teaching in the classroom with radically new methods?

3. What part can and/or should neuroscientists play in the re-design of curriculum ideas for 21st century education. Is the UK educational system and its establishment best suited to the translation of these ideas or are they most likely going to be taken up elsewhere first—in Asia perhaps. If it is clear they confer competitive advantage, what kind of policy driven message should the science community and its most innovative educators be sending out, and when?

4. A major function of teaching is developing pupils' minds so what research outcomes from neuroscience are applicable to supporting this function?

5. What future role do teachers need to play in interpreting the outcomes from neuroscience so that they can used to improve classroom practice?

6. How can the difficulties of bringing together research outcomes from different disciplines be overcome in order to produce a substantive evidence-based approach to improving learning and teaching?

7. Is the education system able to modify its current strategy if there is clear robust evidence that alternate methods of education would provide significant improvement?

8. What are the ethical considerations of changing learning paradigms given our

knowledge that all brains do not appear to be created equally?

9. What are some practical implications of new findings in neuroscience for the education of young children?

10. How do we create more opportunities for empirical bridging research that can explore how emerging scientific insights on learning translate into new pedagogical approaches? What funding mechanisms are required to support this work?

11. How can neuroscience's growing understanding of the brain help us in seeking to address inequalities in learning and skills development and thus potentially to promote greater social mobility?

12. What are cognitive neuroscientists' experiences of working with educational psychologists? What examples are there of 'best practice'?

13. Brain plasticity—the brain is not a fixed entity. The mind can enable to brain to learn and adapt. What is the potential of this and the limitations?

14. How does intention and consciousness impact on the brain?

15. How can meta-cognitive skills best be taught to children, including those with special educational needs, and how may this impact on brain structure?

16. How can cognitive neuroscience contribute to rich explanations of human thought, emotions and behaviour?

17. To support the development of effective critical appreciation of educational neuroscience, what are some of the limitations of cognitive neuroscience methodology?

18. For example regarding neuro-typicality—How is typical is the 'neuro-typical' brain? On what population groups is this based?

19. What can cognitive neuroscience contribute to an understanding of spiritual experiences?

20. Is it likely that we are faced with a situation where the neural networks of the teachers and the neural networks of the learners are out of sync for a generation (at least)—and how would we approach such a problem?

21. How has emerging research on neuroscience considered children's development needs from birth to five and what are the stages which impact most significantly on later life chances?

22. How can our knowledge of Neuroscience help to improve the literacy rates, in which now too many children are found to fail?

23. What aside from learning itself could boost the capacity to learn in adult life?

24. What are the implications of neuroscience for the age at which children should start formal learning? What are the implications for achieving the best mix of different types of learning at different age stages? What can neuroscience tell us about the effects of early stress, neglect or abuse on children's ability to learn, their

behaviour and their ability to develop good relationships with others?

25. What are the main implications of developing knowledge about neuroscience for children aged under 5 and how they are supported to learn and develop?
26. Neuroscientific proof of the brain's plasticity is enormously important for learning across the full lifecourse. What are the implications for education, and what further discoveries can we anticipate?
27. A common complaint by sceptics is that neuroscience research related to education typically shows nothing more than correlation between neural measures and already established behavioural variation—and thus adds nothing new to the picture. How would the panel respond to this criticism?
28. I would like to insight into how to interpret our findings that brain structure changes, within subject, over the teenage years in a task and specific way
29. What evidence have we about the effects of neuroscientific interventions upon development?
    a. Are we ahead of or behind other societies in considering these matters?
    b. Why is there little apparent national level interest from the policy world in these issues?
30. What might be the barriers to adoption of neuroscience based interventions among professionals in education?
31. What programme of research is now necessary to promote progress in this area?
32. Given that cognitive psychology has failed to make a substantial impact on educational practice, why should the even more reductionist and less developed field of neuroscience have a role to play?
33. Given 'the seductive allure of neuroscience explanations' (Weisberg et al., 2008), and given educational fads such as 'Brain Gym', how can neuroscientists guard against crass interpretations and applications of their results? (Weisberg, D., Keil, F., Goodstein, J., Rawson, E. and Gray, J. (2008) The seductive allure of neuroscience explanations. Journal of Cognitive Neuroscience, 20-3, pp. 470–377)
34. When will we get to the point that knowledge from neuroscience is regularly used by classroom teachers?
35. How are positive and negative incentives optimsed in teaching? What are the psychological and neural bases of this? 2. How does educational science view shaping—the progressive establishment of competence in complex domains? Is there a difference between shaping of representations and shaping of actions? 3. Does education acknowledge a distinction between goal-directed or model-based actions and habits? If so, how is instruction structured to favour one or the other? Under what circumstances would one be favoured?

36. What can neuroscience tell me about metacognition and its relationship to other cognitive capabilities?

37. What can neuroscience contribute to our understanding of the manner in which a learner's context impacts upon their learning?

38. If we assume that any representations we have of the brain and its mechanisms necessarily exist within a mind then the claim that mental effects are caused by brain effects appears to imply some circularity. In this context in what ways and to what extent can studying the brain shed light on the workings of the mind?

39. There is research in psychology and education to suggest that the mind is essentially intersubjective and dialogic. This implies that thought is a relationship rather than a thing. In this context how can thought be studied by neuro-science? Are there indirect effects of dialogic relationships that can be observed in brains? Are there indicators of an increased capacity for dialogue or of an increased engagement in dialogue?

40. Roger Penrose has championed the view that mind involves quantum level processes mediated by the brain. If so would this make a difference to the way in which we interpret the evidence of neuro-science in education? Is there any evidence for and against quantum level effects being relevant?

41. What opportunities do you see for educators and educational researchers to collaborate with neuroscientists? How should such collaborations be incentivized?

42. What can neuroscience tell us about identity beyond pointing to networks of neurones?

43. With Dementia in mind: Is there any evidence of a time span or period during waking hours when the brain is more receptive to learning, conversation and or physical action? e.g. after a full night's sleep (drugged or natural) after drinks or food etc?

44. Theories of learning such as Gardner's Multiple Intelligences and the VAK model are taught to trainee teachers, and Ofsted inspectors expect to see them applied in lessons. However from what I can find there seems to be no clear evidence to back them up. Has scientific research been conducted into this? Do these 'theories' have a neurological basis? Should a more scientific approach be taken to education research and if so, how? Should we expect new government initiatives/advice to have been thoroughly researched before implementation? How can we ensure that this happens?

45. How realistic is it to hope that conditions such as dyscalculia will be able to be diagnosed by brain imaging in the next few years?

46. Very interested to know what neuroscience can tell schools about timing of the school day? Also reward structures and how schools can alter them in line with current research? How can we develop a training

programme that can be used to deliver neuroscience ideas to all teaching staff? How can teachers best motivate a teenager to want to learn?

47. Is it currently possible for ordinary classroom teachers to learn some basic elements of the neuroscience of learning that would help them in their day to day work? Or is this an area where a little knowledge is a dangerous thing?
48. To what extent do the panel consider teaching to be an Art or a Science. What does their work on neuroscience have to contribute to their answer
49. Should neuroscience be built into initial teacher training and continuous professional development? If so what ideas do the panel have to achieve this?
50. Can research be married up to those working 'on the ground' so to speak, so that we can measure how the link between brain activity and development impacts on the progression of skills? (At the moment there are too many ad hoc projects which are not impacting on practice)
51. What can we do for those children not born with the same 'learning potential' as others? Is our current academic emphasis the right system in which to 'teach' these children?
52. How can we use the results of current research within neuroscience to improve the life chances of all children?
53. Is it possible to become involved in current research, so that stronger and more meaningful links are forged between neuroscience and education? (It feels as if the results of valuable research are getting lost and not being embraced/used effectively-if at all).
54. Should we be teaching a brain that is not 'mature' enough?
55. What should teachers be teaching to develop neural pathways so that later more abstract concepts such as number can be established?
56. How do you test when a brain a is ready for these things?
57. You ask a child in Year 3 do you remember what you did in Reception they simply cannot remember, so are didactic teaching methods of any benefit at that age?
58. What mechanisms do you propose to get the educationally-relevant neuroscience translated into a form teachers can understand and included in Teachers Training programs?
59. How can those involved in Teacher Training learn about the new knowledge?
60. Is intelligence primarily nature or nurture?
61. I have recently read that children do not have a preferred learning style and that this is a misconception. Children have the ability (if taught) to learn in any given style, is this true?
62. Recently there has been a shift in education to move towards a thematic

approach to learning. Does the panel think this is a wise move?

63. How important is emotional intelligence in a child's ability to learn?

64. Can the panel explain what happens biologically when children learn?

65. How can we improve neurone connection within the brain to improve learning of teenagers?

66. Would the panel like to recommend a research topic for my Educational Doctorate?

67. How can we best help teachers to understand the issue of 'levels of exploration' in research and particularly the potential challenge of over interpretation of neuroscience evidence that has been collected at a micro-biological level rather than at a social process level?

68. The average teacher works with classes of 30 or so children. Brain research is a window on to how many of these children learn but there are dangers inherent in classifying, categorising and pigeon-holing. We still know relatively little about the workings of the individual brain and each child is different. How can we ensure, in bringing neuroscience research and education together, that each individual child with his/her unique brain, gets the best chance possible to achieve success in school?

69. Is there any factor OTHER than brain that should have to do with education? What are the issues that should make us think that education may NOT have to do with studying the brain?

70. Will there ever be a time when we can implant knowledge into the brain via some sort of transfer? ie. will there be a way to skip the learning process and just 'download' lesson plans?

71. Some neuroscientists have called for teenagers' lessons to start later in the day, to make allowances for the fact they really are sleepier in the morning. Are there any other timetable changes that could be made for different age groups, so as to optimise their ability to learn?

72. Are there any findings from lab-based educational neuroscience that have been rejected in the classroom (akin to the tension between evidence-based practice and practice-based evidence in mental health)? If so, how can these contradictions be resolved?

73. One of the buildings shortlisted for the latest Stirling Prize for Architecture is a school, the design of which has apparently contributed to striking improvements in pupils' learning and behaviour. Is there any neuroscience/ psychology research on ways that school design and layout can affect pupil learning and behaviour?

74. How can neuroscience inform the debate on nature versus nurture in education?

75. If neuroscientists and professionals in education are to work together to enhance progress then it would seem to be essential that individuals in both

areas meet at regular intervals. Would this be possible? Perhaps there could be sessions during the vacations.

7. Ten example claims from neuroscience that might impact on education

1. **Neuroscience is concerned with the impact of biology but does not ignore the impact of the environment.** Many people are reluctant to consider the possibility that differences in learning ability in children or adults might have a genetic or biological basis. However, neuroscientists point out that it is wrong to assume that learning outcomes are *solely* determined by the learning environment. This would mean that the environment is held responsible if learning fails and parents and teachers often get the blame. Instead, research shows that biological factors play an important role in accounting for differences between people. If we seek to improve outcomes of teaching, we need to consider biological factors that underpin individual differences.

Example: Research has shown that some children who have specific difficulties with language, literacy or maths differ from other children in terms of both genetics and aspects of neurobiology. This runs counter to the view that specific learning difficulties are just social constructs. Thinking of environmental causes alone means that we will never discover the optimal way of teaching those children whose learning difficulties have an origin in the genes and in the brain (see point 2).

2. **A biological basis does not imply determinism or immutability.** We have long known that it is possible to correct for short sightedness by wearing glasses. This makes clear how a genetic condition is treatable with environmental intervention.

Example 1: Children with dyslexia can make progress in reading by relying on unusual strategies to decode words. Research showed that these strategies are underpinned by the inferior frontal regions of the brain. The better the dyslexic child's reading the more active this region is, although it plays almost no role for non-dyslexic readers. This finding suggests that such children would not benefit from being taught in the same way as other children. Neuroscience techniques can be used to track the effects of remediation.

Example 2: Children who have cochlear implants because of genetic problems in hearing vary in the extent to which they learn to understand speech. This can be traced back to differences in the regions of the brain responsible for working memory rather than regions concerned with discriminating speech sounds. So training working memory skills might be more effective than training auditory skills.

The examples suggest that the differences between failing and successful children cannot be removed by just giving them 'more of the same': they have different neurobiological strengths and weakness and this will require different educational approaches.

3. **Neuroscience demonstrates how teaching changes the brain.** Brain

function and even anatomy can change, perhaps permanently, as a result of teaching in a particular cultural context.

Example 1: English readers show different activation patterns in the brain's reading system compared to Italian readers. This is because the languages differ in the complexity of sound-letter relationships. The reading system of the brain is readily configured to adapt to these differences, and differences are even more obvious in Chinese readers.

Example 2: Adults who were trained to read music to play a keyboard showed activation in the inferior parietal region after 3 months (or even less time), which they did not show before.

4. Brain development and plasticity. Recent research has shown that the brain is far more changeable or 'plastic' than previously thought even though there are limits that still need to be explored. New cells grow in some parts of the brain; connectivity between cells changes continuously; there are repeated phases where connections first grow and are then pruned back. One of these phases includes adolescence. Plasticity has implications for life-long learning, but we still have insufficient knowledge of its extent and its limits.

Example: Research has shown structural changes in the brains of licensed London taxi drivers who acquire 'The Knowledge' as adults. They reversed after retirement. This demonstrates the principle of 'use it or lose it' (see below).

5. Practice makes perfect, as demonstrated by many studies of both theoretical and practical learning.

Examples: Neuroscience shows that there are separate neural circuits that influence intended and automatic behaviors; and as practice proceeds there is a switch away from the circuitry that underlies the intended behaviour toward that used for automatic behaviour.

6. The role of reward in learning: Neuroscience has provided new leads in the way the brain interprets rewards. These insights can potentially be exploited in technological advances such as improved design of learning games (See point 9).

Example 1: The anticipation of reward can support learning. If there is some uncertainty about receiving a reward, this can be particularly motivating.

Example 2: Not everybody is equally sensitive to reward and equally able to monitor their own errors during learning. These differences have a basis in the brain.

7. Learning by social reinforcement. Learning can be promoted by purely social rewards.

Example: monkeys learn not only for food rewards but for the opportunity to see images of other monkeys. These positive reinforcers activate the same circuits in the brain as primary rewards such as food or money.

8. Resilience. Attempts at counteracting the effects of adverse social and environmental factors are made

constantly. This works with some cases but not others. Research suggests that internal biological factors such as temperament and self control may be critical and vary between individuals. Research is still in the early stages, but seems to confirm that education can build up an individual's cognitive reserve.

Example: Cognitive reserve is crucial in aiding recovery after brain injury, and can counteract the effects of ageing.

9. Much of what we attend to and learn is below our awareness: many different things can grab our attention and we even take in things we don't want to learn about. Neuroscience has found ways to predict which things are likely to be learned and retained and which are not. The brain basis of how we consciously control learning and attention and of the learning that happens subconsciously is a topic of neuroscience.

Example: Not only can conscious control influence (top down) what we attend to, but so can subconsciously perceived stimuli (bottom-up). The possibility of training mechanisms of top-down control is being studied.

10. Boosting brain power. Education across the life span is a powerful tools to boost brainpower. Brain power can be boosted using both traditional methods and new technology. Researchers are looking at the effects of sleep and exercise, and also at the effects of training via games to enhance working memory, top-down control of emotions, cognitive reserve and to inhibit risky or impulsive behaviour. Smart drugs are increasingly used by students. Ethical and health implications need to be debated.

Examples: Older people who did 4 months of intense aerobic training showed improved memory hippocampal blood flow, which underpins memory. Studies on the effects of learning after sleep in the brain are currently a focus of research. Attention has shown to be amenable to improvement in video game players.

Obstacles to the understanding of neuroscience:

The Mind–Brain Divide. Neuroscience is trying to overcome this divide. Research shows that it is possible to cross the divide in either direction. We need to be aware of certain fallacies:

Examples: The fallacy that for problems with a biological cause we think drugs are appropriate, and for problems perceived as social we think psychological methods should be used. The fallacy of thinking that teaching is not a case of cognitive enhancement, but smart drugs are.

Too early to say? Basic science is still progressing with practical implications far off in the future. There is currently a huge gap between secure knowledge and application of research in the classroom. Teaching cannot wait for science and we urge caution in the enthusiasm to apply so-called brain based methods. But, we need to acknowledge that there is a lot of demand from teachers and parents to know more, and if neuroscientists are too cautious and don't say anything, someone else will.

Draft by Uta Frith with substantial input from the Working Group and other interested neuroscientists.

29 July 2010

8. Preliminary analysis of the Twitter feed

The points listed below comprise some of the 600 live Tweets logged during the Brain Waves Module 2 discussion meeting held on Thursday 7 September 2010 – 'Education: what's the brain got to do with it?' These comments have been sorted into seven broad categories, which are:

1. Interdisciplinary Collaboration and Communication
2. Current Perceived Barriers
3. Education Landscape including Teacher Training and CPD
4. Potential of Neuroscience
5. Issues concerning Individual Differences
6. Issues concerning Life Stages, Sensitive Periods, and Lifelong Learning
7. Public Engagement

Please note that the views outlined below do not necessarily reflect the policy positions of the Royal Society or the Wellcome Trust

1. INTERDISCIPLINARY COLLABORATION & COMMUNICATION

Thirst amongst teachers to engage with researchers

Teachers not being given the theoretical research basis

Teachers would welcome ways of contacting researchers to find out about latest research and to direct future research

No facility for feeding research into education—what about periodicals?

If offered an opportunity to do something that enhanced their teaching, they would do it

Do researchers know what goes on in the classroom?

Important to mix understanding of neuroscience with actual teaching classroom practice

How do we turn what we know about neuroscience into something practical

Researchers need to join conversation by being more practical

Need to apply the research in a real way

Need to produce something with practical implications

How can we apply new knowledge to education just as clinical might use new information on kidney or heart?

Scientists can't work independently—need to see how ideas translate into practice

Neuroscience on its own doesn't have transferability

Monkseaton school looking at circadian rhythms and have changed their school day

Articles need to be written by teachers and neuroscientists together

Knowledge need to go in both directions—maybe neuroscientists need a masters in education!

Teachers become cynical—when no one asks them what works!

As a teacher, change seems to come without being told the reasons behind it. Frustrating

Questions need to come from the teachers?

How do people in education formulate questions that neuroscientist can work with?

Neuro and education researchers are starting from different point and looking at different problems, but some overlap

Education researchers would like to collaborate

Conversation between science researchers and education researchers?

Educational psychologists—already doing good work in schools—so already some links to be capitalised on

Who could facilitate the links between education and neuroscience researchers?

Needs to be a dialogue, not just presenting solutions

Conversation between neuroscience and educators is about mutual benefit and help for each other

Interesting that people in different fields define things differently e.g. skills

Need a group to get together to build a basis for a shared language

Linguists are missing from the wider conversation—primarily language is most prevalent way we learn. Need to relate more to the neuroscience.

Teachers have to translate concepts and ideas into a language that is understood by pupils

Need better interactions between all of the groups

Cooperation between different agencies is essential

The key is working together—but how to do it?

We need input at the translation stage—what are the mechanisms to achieve this?

Key: developing and implementing structures to enable discussion between fields

Different groups could start off collaboration. Who could champion these links? What could incentivise the collaborations?

Interdisciplinary work is hard because each group has different motivations

Educational research to go through a gating system to assess usefulness to teachers?

Would it be helpful to have something like the equivalent of NICE to assess the different approaches?

Need a review of what is currently happening—journal needed?

Would a peer-reviewed newsletter be helpful?

How do you get teachers to read a newsletter?

Need for a journal or magazine that ends up on teachers' desks with research they can use

Need a guide on which brain functions teachers should be looking for

Getting the head and deputy head involved so they can diffuse it downwards to the teachers

Do teachers want to know what works, or to see the evidence behind it?

Don't need to know the science, need to know what works, and be able to trust that the source is reputable

Teachers need to be confident that the research findings are relevant

Database of proven practices and methods

As a teacher, wouldn't it be useful to take things into classroom & report back? If organisations can say that neuroscience is worth looking at and suggest small projects, might be a good first step

Can teachers try out some ideas? And feed back to researchers?

Teachers willing to try but lots of different approaches and lots of change

Little evidence of government strategies helping teachers access research

Getting the message across in policy is the challenge

How do we bridge the gap between scientists and policy makers?

Government departments need to be better communicating what they want from the scientific community

Talking about the gap between the science and devising policy

Good news is some government departments are eager to work with the researchers to get evidence!

More secondments of scientists with government? Workshops with government and scientists

Government needs to prescribe some methods sometimes to make schools use proven programmes

Role for someone to bring teachers, researchers, and policy makers together. Essential.

2. CURRENT PERCEIVED BARRIERS

Neuroscience does not seem to be leading, but following in terms of what people already feel

If compare with clinical trial—specific to one phenomena. Teachers and skills working on multiple variables!

Teachers need time to take general material to apply to the specific of their pupils—time they don't often have

Difficult to find link from research to education practice. Teachers often don't have time to identify individuals for research

Hard for schools to spare the best teachers' time

Hard for teachers because they are faced with mixed ability groups, then are limited by the constantly changing curriculum

Need to avoid blaming of pupil, teacher, or parent as a result of imaging

Some types of brain damage could have different causes that can complicate interpretation of neurological analysis

Lots of research makes assumptions on what's normal and what's a deficit

Science vs social science—serious tension! Resistance and prejudice needs to be overcome. Reductionism/ determinism a problem.

Nothing is replicable because no two children are the same

For teachers, personal anecdotes is powerful evidence

Teachers know a lot about individual learners but neuroscientists don't

A common misconception that neuroscientists only deal with averages—eg model of an average brain for social context

Stories are clinical rather than practical—sound too remote and not relevant to people's lives

Research is not being carried out in classroom conditions so is it accurate?

Few studies based in a real world setting because of difficulty to control

Hard to link research to what goes on in schools

Research in schools requires consent. Respecting privacy. Data management.

Would research in classroom be seen as experimenting on children?

Hard to marshal robust findings vs flimsy findings

fMRI studies can be over-interpreted to imply determinism about later life that isn't justified

Lots of things we know but don't make it into policy—different sort of evidence that is more persuasive

Silos problems amongst government departments

Some of the programmes and strategies are very expensive and even after proof that they work it's hard to get them diffused

Messages can get distorted by people who have a financial interest

Problem with neuroscience—so much aggressive marketing—so need peer review?

Lots of neuromyths

We need to bust neuroscience myths

Have to get rid of old wives' tales

Difficult to know from the neuroscientists what to believe

Neuroscientists need to get more involved in correcting the myths

Science interesting but terminology can be misused

How can non-specialists decide what to believe, when there is disagreement within the field?

If something doesn't work, hard to make up for lost time

3. EDUCATION LANDSCAPE, INCLUDING TEACHER TRAINING AND CPD

Does our education system foster continual learning giving that it 'tests'?

Need to escape target culture?

The issues with assessment in education are its limits and the high stakes associated with it

We spend years training our doctors in research, what about teachers?

Trainees are taught little to nothing about the science of the methods for teaching

Does initial teacher training need to be rewritten?

Oral language is a key underpinning area—this is not well covered in teacher training

Agreement that initial teacher training too short

Need to address teacher training, but then only get to the new teachers

Training not thinking critically about what things work and why

At the moment, initial teacher training very prescriptive

What impact is research having on teacher training?

Link CPD for teachers to universities?

Is CPD there just to push policy through?

CPD in schools—not great, no funding. Not enough time given for real research.

Masters qualification would be good—educational neuroscience a new field

Can someone please develop a CPD training pack?

What info can we give to teacher trainers?

Need to teach specific techniques to teachers to allow them to make use of neuroscience

4. POTENTIAL OF NEUROSCIENCE

Measurement methods are often flawed, so often don't measure what they're meant to—could brain imaging avoid this?

Brain imaging very exciting if can notice individual difference to work out implications for early interventions

Early intervention due to identifying potentially liable individuals would be helpful

Missing in research about kids' ability to process instructions. Neuroscience should have something to offer here.

Need to know links between neural and environmental factors

Any way of debunking false claims in marketing of some mind gyms? Researchers are being more careful about what they claim than those who market products such as brain training

Brain plasticity needs more research—range of opinions about what's known

Need more help with brain imaging, to distinguish between developmental or neuro issue

Brain imaging is a visual way of seeing differences in those with learning disorders—well developed in dyslexia, less so in dyscalculia

There is a lot of work being done on dyslexia, we know how to help children who suffer from it

Neuroscience as a behavioural factor? Critical to understanding of pupils' behaviour

How to assess children's latent abilities without looking at their current attainment levels

Good teachers recognise importance of rehearsal etc, but now neuroscience gives evidence to this

Can neuroscience tell us why some life-long learning programs work? Is it the content, or the process?

Promise of neuroscience—to look at the difference that different teaching regimes make

Brain science provides basis for classroom research

Neuroscience can be defined in many different levels—e.g. whole brain, to neuron/cellular level

5. ISSUES CONCERNING INDIVIDUAL DIFFERENCES

Sets of genes might affect brain structure

Genetic helps explain that everyone is different

Are we interfering with the idea that everybody is different

fMRI studies can be overinterpreted to imply determinism about later life that isn't justified

Agreed genetics is a dirty word

Environmental conditions and interactions with genes important

Genetic make up can bring things to the situation, but you can also teach people to aid in cognitive reserve and resilience

Genetics is just a label for a wider debate

How strong is the taboo on genetics and education? What's the impact of the taboo?

6. ISSUES CONCERNING LIFESTAGES, SENSITIVE PERIODS, AND LIFELONG LEARNING

Maybe we start school too early, can research tell us anything about that?

Critical period might be neural and amount of time you need to learn something

What is the evidence for critical periods and windows of opportunity?

All children develop strategies—should start to identify better strategies at an earlier age regarding thinking skills and calculating

Difference between the child brain and the adolescent brain, so may need different methods

Focus can often be about childhood but education must be thought of as a lifelong endeavour

We need to think about what happens outside of the classroom too and beyond school age

OECD project shows the brain is plastic and this is scientifically shown

Learning is a plastic process

Evidence from animals and humans does show that new neurons can be born

Plasticity changes throughout life of the brain

There are different levels of plasticity, can mean physical changes in the brain or small changes in terms of neurons interacting

Learning skills should extend to skills needed for work, should also be interested in longevity and other areas

A lot of people are not in education or in employment, how can we apply this to those people?

Resilience and confidence—could be very important, perhaps in getting people back to work. . ..

Need to think of skills of older workforce

How can we help people to carry on doing what they are doing in the workforce for longer?

Older people can learn—need to reinforce this idea

You are never too old to learn

Learn in different ways as we age—very relevant to the ageing workforce

Participation in adult learning drops off rapidly after 50 despite what we know

Topical because of issues around late retirement

Talking about the importance of lifelong learning. . . e.g. learning homes having to prove their efficiency to government

Need to invest in young so that we won't have dementia in so many years

Use it or lose it is so true in dementia

7. PUBLIC ENGAGEMENT

Need to show importance to the public

Public needs to know what neuroscience really is—understanding of the word made accessible

What impression does the public have of neuroscience?

What issues can we engage the wider public in?

How do we get translation for society?

Media can be a driving force for change

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ISBN 978-0-85403-880-0

9 780854 038800

ISBN: 978-0-85403-880-0
Issued: February 2011 Report 02/11 DES2105

Founded in 1660, the Royal Society is the independent scientific academy of the UK, dedicated to promoting excellence in science

Registered Charity No 207043

Price £20