Research Conference

2013

How the Brain Learns:

What lessons are there for teaching?

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ACER

Australian Council *for* Educational Research

CONFERENCE PROCEEDINGS

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FOREWORD

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GEOFF MASTERS

Australian Council for Educational Research

Professor Geoff N Masters, BSc, MEd, UWA, PhD Chicago, FACE, FACEL. Geoff Masters is Chief Executive Officer and a member of the Board of the Australian Council for Educational Research (ACER) – roles he has held since 1998. He has a PhD in educational measurement from the University of Chicago and has published widely in the fields of educational assessment and research. Professor Masters has served on a range of bodies, including terms as founding President of the Asia-Pacific Educational Research Association; President of the Australian College of Educators; Chair of the Technical Advisory Committee for the International Association for the Evaluation of Educational Achievement (IEA); Chair of the Technical Advisory Group for the OECD's Programme for International Student Assessment (PISA); member of the Business Council of Australia's Education, Skills and Innovation Taskforce; member of the Australian National Commission for UNESCO (and Chair of the Commission's Education Network); and member of the International Baccalaureate Research Committee. He has undertaken a number of reviews for governments, including a review of examination procedures in the New South Wales Higher School Certificate (2002); an investigation of options for the introduction of an Australian Certificate of Education (2005); a national review of options for reporting and comparing school performances (2008); and reviews of strategies for improving literacy and numeracy learning in government schools in Queensland (2009) and the Northern Territory (2011). He developed the National School Improvement Tool endorsed by education ministers in December 2012. He is the author of Australian Education Review number 57, *Reforming Educational Assessment: Imperatives, principles and challenges* released in March 2013. Professor Masters was the recipient of the Australian College of Educators' 2009 College Medal in recognition of his contributions to education.

ACER's annual Research Conference is designed to review current research knowledge in a key area of educational policy and practice.

Research Conference 2013, on the theme 'How the Brain Learns: What lessons are there for teaching?', brings together leading researchers in neuroscience, psychology and education to explore effective teaching and learning practices in the light of current knowledge about basic learning processes and factors that influence successful learning. This field of research, often referred to as the 'science of learning', is developing rapidly and has the potential to enhance significantly our understanding of learning processes and their implications for teaching.

The papers from *Research Conference 2013* reflect the multidisciplinary nature of this field and the growing collaboration between researchers in disciplines such as neuroscience, psychology and education. They also suggest fruitful areas for further collaborative research, including through the newly established national Science of Learning Research Centre.

A key feature of the Science of Learning Research Centre – a collaboration led by the Australian Council for Educational Research, the Queensland Brain Institute at the University of Queensland and the Graduate School of Education at The University of Melbourne – is its cross-disciplinary approach, which will include collaborating with teachers to build a scientific evidence base in the areas of learning and teaching.

We welcome you to *Research Conference 2013* and trust that you find the research presentations and conversations with other participants stimulating and professionally rewarding.

Professor Geoff N Masters
Chief Executive Officer, ACER

SCIENCE OF LEARNING RESEARCH CENTRE

PLENARY PAPERS

OUR LEARNING/TEACHING BRAINS: WHAT CAN BE EXPECTED FROM NEUROSCIENCE, AND HOW? WHAT SHOULD NOT BE EXPECTED FROM NEUROSCIENCE, AND WHY?

BRUNO DELLA CHIESA

OECD and Harvard Graduate School of Education

Educators and neuroscientists are now working together to understand how learning and the brain are related, and how this interconnectedness will better inform our educational policies and school systems. Bruno della Chiesa, visiting lecturer at HGSE and a senior analyst at the Organization for Economic Co-Operation and Development (OECD), has been a pioneer in the development of this field. Della Chiesa conducts educational neuroscience research, collaborates with researchers worldwide, and writes books and papers that synthesise the research that has been done to give us insight into why educational neuroscience is important to the future of learning, and where future directions might lie for the field.

A former diplomat and science-fiction editor, Bruno della Chiesa is a linguist trained at the universities of Bonn and Paris Sorbonne. After his studies in France and Germany, he lived in Egypt, Mexico, Austria, France again, and in the USA. A self-defined 'pluri-cultural European', he speaks (and writes in) English, French, German and Spanish.

After more than a decade in the French diplomatic service, he joined the OECD and – in 1999, within the Center for Educational Research and Innovation (CERI) – founded the Brain Research and Learning Sciences project, considered a seminal work in the field of educational neuroscience. This led to the publication of his book, *Understanding the brain: The birth of a learning science* (OECD, 2007).

He subsequently started teaching a yearly course entitled 'Learning in a globalizing world' at Harvard Graduate School of Education (HGSE). He created and directed the Globalization, Languages and Cultures program, an HGSE-CERI cooperation, culminating in the publication of *Languages in a global world – learning for better cultural understanding* (OECD, 2012).

Bruno della Chiesa continues to work in the field of neuroscience as an editor for the *Mind, Brain, and Education* journal, and has embarked on a new endeavour that deals with future international perspectives in math and science education as related to civics, while heading International Studies at Ulm University ZNL in Germany. His work on 'promoting and raising global awareness' links educational neuroscience, language didactics, sociolinguistics, international policy and the philosophy of ethics.

Understanding (and thus, in my view, learning) is an intense pleasure for the human brain, particularly in children, from a very young age … and even at school, if possible! Albert Einstein is said to have considered it a miracle that curiosity in young human beings survives school. Unfortunately, there seems to be at least some grain of truth to this pessimistic stance. Can neuroscience help us maintain or even develop this wonderful human characteristic? If yes, how? If not, why? If 'maybe', where to draw the line?

First of all, why take interest in neuroscience? Thanks to brain-imaging technologies, we have learned more about the functioning of our brain over the past two decades than during the whole of human history. Various important discoveries around two crucial notions – brain plasticity and 'sensitive' periods – cannot be disregarded when it comes to learning (della Chiesa, 2008). Given that we now also have a better understanding of the strategies developed by the brain to manage emotions and control higher order functions, it is no longer possible to ignore this new knowledge when making decisions on educational policies and practices (even if there is of course a lot more to discover about the brain, and even if neuroscience does not make other, more traditional knowledge from reference disciplines – social sciences – obsolete). Not taking into account what is known leads to missing out on potentially important insights (Fischer et al., 2007; OECD, 2007).

Back in 1999, it became obvious to some that a dialogue was necessary, on an international level, between the neuroscientific communities on the one hand and the education communities on the other in order to answer questions of technical and scientific, social and economic, ethical and political natures. This is how the 'Learning Sciences and Brain Research' project (1999–2008), to investigate how neuroscience research could inform education policy and practice, was born within the Organization for Economic Cooperation and Development's (OECD) late Center for Educational Research and Innovation (CERI). This transdisciplinary project brought many challenges: within the political community, participation in the project varied, with some countries resisting approval of the project altogether, at least during the first years; in the neuroscientific community, participants struggled to represent their knowledge in a way that would be meaningful and relevant to educators; within the educational community, response to the project varied, with many educational researchers resisting it for fear that neuroscience research might make their work obsolete. Achieving dialogue between these communities was even more challenging. One clear obstacle was that participants had difficulty recognising tacit knowledge in their own field and making this knowledge explicit for partners in other fields (della Chiesa, Christoph & Hinton, 2009). Thanks to goodwill on most sides, after a necessary warming-up period of observation, the dialogue started off rather well – and as a two-way street, to crown it all (OECD, 2007). But there is of course still a lot more to do (to build a roundabout, an ascending spiral …), especially given that such an open dialogue is now even more necessary than 15 years ago. In the upcoming decades, we will be confronted more and more with the following question: how do we inform citizens (parents, teachers, policy makers and others) about arcane subjects of such complexity that they can hardly be understood by anybody (della Chiesa, 2010)?

A child is born with 100 billion neurons (1011), but it seems that only 10 per cent of the neuronal connections (synapses) already exist at birth. The other 90 per cent are developed throughout life. In an adult, 1 million billion synapses (1015) link these 100 billion neurons, with an average of 10 000 synapses per neuron. And yet only 6000 genes are involved in the development of the brain: they alone cannot be responsible for the generation of billions of synapses. What shapes the neuronal structure is experience: not only learning experience but also experienced emotions – in short, everything that makes an individual's history. Of course, synaptic constructions are very dependent on the environment, be it the family, the school or the society in general. All brains are extremely promising at birth – but the individual path will positively or less positively determine what follows (Toscani, 2012).

This plasticity not only turns the brain into a fabulous lifelong learning device (Neville & Bruer, 2001), but it also makes remediation of certain learning deficits possible, even if they are not diagnosed early (although in certain countries, it is possible today to diagnose children with, for instance, a risk of developing dyslexia before the age of 12 months, which of course makes things a lot easier). Because it is during infancy that the synaptic development is the most significant; this period of life is even more important than others in terms of brain development. But it is definitely not true that everything is determined by the age of three years (or six, or 10), as is said sometimes (Bruer, 2002; Toscani, 2012). This kind of 'neuro-myth' (OECD, 2007) make parents and educators feel anxious, if not guilty, for the (dubious) benefit of a few others. Fortunately for us all, the brain remains plastic way beyond childhood and adolescence. For example, it is now known that the functional maturity of the brain goes on until the third decade of life: the prefrontal cortex, involved amongst other things in managing emotions and planning, is generally not mature before the age of 25 (but there are great individual differences, as always). This biological phenomenon explains, in part, certain attitudes of adolescents, and reinforces the notion that there is hardly a worse time in life than adolescence to make long-term decisions, let alone decisions for life (OECD, 2007), yet our education systems (and our social functioning) usually require our young people to make such choices, that are often irreversible, especially in terms of orientation ('tracking') (Bergier & Francquin, 2011; Toscani, 2013).

Deterministic views still poison our understanding of the learning brain. As an example: intelligence is still often evaluated by what is called IQ. What does the use we make of IQ tell us about our representation of the human development, or about our belief in human perfectibility (della Chiesa, 2013) and thus in educability (Toscani, 2013)? What exactly does IQ measure, and whom or what does it serve? Is it not a means to perpetuate the categorisation of human beings? Are we still prisoners of the equation IQ = intelligence = academic and professional success (Toscani, 2012)? IQ is an artificial creation supposed to measure 'intelligence', which allows a snapshot diagnosis of specific cognitive functions – at best, of one (maybe two) of our eight (or more) 'multiple intelligences' (compare Howard Gardner's work). Tracking 'choices' for students with cognitive difficulties are founded on such scales of measurement that say nothing about their potential to develop, and actually change, over time. In the same sense, many tend to think that a child with learning difficulties does not possess the cognitive capabilities required to treat information at an operational level. Therefore, the child is put into a more 'adapted' class, is given easier tasks, and thus the child's incompetence is confirmed, and even reinforced – even, and most importantly, in the child's own eyes: self-fulfilling prophecies follow. But today it should be possible to understand that an inadequate treatment of information at school is mainly due to external phenomena: the child does not speak the language of the school or does not have the same culture (Christoph, 2012), or does not use the forms of intelligence privileged by the school (logical-mathematical and logical-verbal intelligence).

All this, reinforced by an evaluating (often devaluating) look, does not motivate the child to develop adequate cognitive behaviour. Often this point of view is opposed by the argument that IQ tests have been further developed. But they are still tests based on more than doubtful calculations. Political decision-makers have a hard time with the subject of IQ or its more 'presentable' derivations or by-products (quantophrenia in all its forms), persisting to condemn generations of children with difficulties by tracking them on the sole basis of a 'fixiste' conception that amounts to denying any potential.

This leads us to the debates concerning existing or future policies. When we have ethical decisions to make, on an individual or on a collective level, these are situated on a good–bad axis. From ethics derives politics, which can be expressed on a desirable–not desirable axis. From politics derive policies that are situated on a feasible–not feasible axis. From policy measures derive practices that lie on an efficient–inefficient axis. This, how I see a decision-making process is, of course, extremely schematic. But science will not tell us what is good or bad, what is desirable or not, be it for a child or for any human being. That is the role of ethics, thus of politics and thus ultimately, in a democracy, the citizens' responsibility. It is not up to research to solve problems of policy and practice, not even to suggest solutions (della Chiesa, 2010). Yet research, be it in neuroscience or in other disciplines, is not useless, as it at least allows new light to be shed on old debates and new questions to be asked.

But using this new light causes another difficulty. When trying to get across a scientific message to politicians, practitioners or the general public, we are obliged to use the media, which due to its logic of discourse that is incompatible with the constraints of scientific discourse, oversimplifies to the point of distorting messages, often even completely misinterpreting what is being said (Bourdieu, 1996; Chomsky & Hermann, 1989; della Chiesa, 1993, 2010).

In no case must science replace ethics when making a decision. We know only too well – if history has taught us anything – where this leads. But we need enlightened citizens more than ever before (and educating a citizen starts from the youngest age, of course); our societies are confronted with enormous challenges, especially since the questions we need to answer are more and more complex. The survival of our democracies in the 21st century may actually depend on how we will manage to rise to these challenges, in living not only as responsible citizens, but as ethical human beings enlightened by a genuine cultural and global awareness (della Chiesa, 2012; Noddings, 2005; Stein, della Chiesa, Hinton & Fischer, 2011), thus becoming, as Goethe put it, 'who we are' ('*Werde, wer du bist!*').

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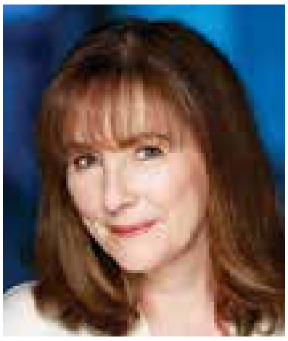
THE WOMAN WHO CHANGED HER BRAIN



BARBARA ARROWSMITH-YOUNG

Barbara Arrowsmith-Young is recognised as the creator of one of the first practical treatment applications using the principles of neuroplasticity. As the founder of the Arrowsmith Program, she began using these principles in 1978 to develop cognitive programs to deal with learning disorders, first starting with her own debilitating set of brain deficits. In her presentation she will talk about her journey of discovery, the lines of research she combined and the outcomes achieved over her 30-plus years as an educator and researcher. She will describe a number of learning disorders, from those that affect the learner in school to those that affect us in life. She will discuss 'cognitive glitches' – those areas of weakness that we are all familiar with and often explain away by saying, 'I am just not good at navigating/recognising faces/[fill in the blank]'. She will discuss 'cognitive mismatches' – situations we find ourselves in where the demand of the task is incompatible with our cognitive functioning and the challenges this presents. The nature of the transformation that occurs as the function of deficit areas are stimulated through cognitive exercises will be presented.

This talk will cover the personal and the universal. The personal is Arrowsmith-Young's journey of discovery driven by her hunt for a solution to her own debilitating learning disorders. The universal is that we all have a brain and, by furthering our knowledge of how our brain shapes us through mediating our understanding of the world, we can gain insight into our functioning and that of others. And, most promisingly, through our growing understanding of neuroplasticity, we now have the knowledge to develop treatments to shape our brains.

ABSTRACT

Neuroscience research can inform us in many ways. It can tell us about normal cognitive development: what regions of the brain and networks are critically involved in certain aspects of behaviour and learning. It can inform us about abnormal development: what regions are not functioning normally and those that could benefit from intervention with the goal of improving function in order to allow individuals to learn effectively. Through understanding the nature of various cognitive functions, we can create cognitive programs to stimulate and strengthen the functioning of these areas using the principles of neuroplasticity with the goal being to enhance functioning where it is needed to allow learning to proceed.

Neuroscience can provide knowledge about brain mechanisms and processes that can be used to enhance or improve learning. The application of this knowledge needs to be guided by careful research so that the practices are sound and of benefit to the learner.

This is an exciting time for educators and neuroscientists as we explore how to translate what we are learning into positive learning experiences. This knowledge has the potential to show us how we can change the capacity of the learner to learn.

The pursuit of developing neuroplasticity-based interventions for education and learning will benefit from – and best serve our students if there is – strong collaboration between researchers, educators, parents and the students themselves.

The concept of *neuroplasticity* or *brain plasticity* might feel new but that's because in the last few decades there has been a proliferation of mainstream writing taking neuroscience research findings out of the laboratory and into public awareness. In fact, research in neuroplasticity has been under way for more than 200 years. Santiago Ramón Y Cajal (1852–1934), one of the great pioneers in neuroscience, theorised the concept of neuroplasticity long before we had the refined technology and techniques to demonstrate it. Cajal knew, but could not prove, that the brain can be remapped, its very structure and organisation changed by the right stimulation.

'Consider the possibility', he once said, 'that any man could, if he were so inclined, be the sculptor of his own brain, and that even the least gifted may, like the poorest land that has been well cultivated and fertilized, produce an abundant harvest' (Cajal, 1999, p. xvi). This Spanish neuroscientist won the Nobel Prize in 1906. Almost a century later in 2000, Eric Kandel won the Nobel Prize for his work, which confirmed Cajal's hypothesis that the brain is plastic. Kandel demonstrated the growth of new synaptic connections as a result of learning in response to environmental demands.

Neuroplasticity, simply put, is the brain's ability to change structurally and functionally, in response to stimuli – to grow dendrites, to make new neural connections, to alter existing connections, to grow new neurons (neurogenesis). Neuroplasticity provides a mechanism through which we can fundamentally change the brain's capacity to learn and to function (Cramer et al., 2011; Kays, Hurley & Taber, 2012; Lillard & Erisir, 2011; Lövden, Backman, Lindenberger, Schaefer & Schmiedek, 2010).

Neuroplasticity as a process can lead to changes that affect functioning in either positive or negative ways.

> *When confronted with major changes or challenges, the brain can adapt by remodeling and refining existing connections. Communication pathways can be strengthened or enhanced by outgrowth of dendrites, axonal sprouting, and increasing or strengthening synaptic connections. Conversely, various factors can contribute to loss of synapses, shrinkage or retraction of dendrites (de-branching), and pruning of axons, thereby reducing communication in those areas. (Kays et al., 2012, p. 119)*

In order to harness neuroplasticity for practical applications, we need to understand what research has shown to be important factors in evoking these neural changes. We need to investigate how we can effectively reduce the factors leading to negative neural changes and increase the factors leading to positive neural changes.

Some of the factors leading to negative brain changes are chronic negative stress, prolonged anxiety, chronic pain and certain mental illnesses. Some of the factors leading to positive brain changes are active sustained engagement in the learning process, environmental enrichment, task demand or effortful processing or both, novelty and complexity, exercise and reward and performance feedback systems.

We know that there is variability in brain plasticity and research is looking at genetic factors that may play a role. Individual differences related to dopamine, a neurotransmitter that plays an important role in plasticity, are being investigated (Pieramico et al., 2012; Söderqvist et al., 2012).

We know that any learning process involves the brain – when we plan a trip, read a book, solve a maths or word problem, we are using our brain. However, not all learning experiences are equal in causing lasting and meaningful brain change. There are important questions to investigate:

- what is the difference between what happens in the brain in the normal course of using it and what happens as the result of very specific targeted experiences?
- what is the nature of the experience/learning/process/intervention required to lead to long-term functional

differences that affects the individual's ongoing and future learning and cognitive processing?

In a similar way that short-term anxiety or stress or acute pain lead to immediate changes in the brain, it is the long-term exposure to these conditions that leads to the significant long-term negative effects that Kays et al. (2012) noted. Lillard and Erisir (2011) speak to this:

Whether those changes are very temporary, involving mainly synaptic strength and temporary facilitation or inhibition, or entail longer term change in the numbers of synapses in a cortical field, has importance for how those connections will be used. If one wants only a temporary trick, it can be induced quickly; if one wants it to last, it must be induced gradually, allowing for harder neuroplastic change. (p. 231)

Regardless of the source, a sustained change in a pattern of neural activity is a necessary trigger for neuroplasticity. The change in neural activity pattern leads to a reorganization in neural circuits, which produces long lasting functional change. Thus, the capacity of neural circuits to reorganize (neural malleability or neuroplasticity) enables the brain to use its internal resources more efficiently to respond to external information as a new repertoire of behaviors. (p. 208)

Research is investigating the factors involved in harnessing neuroplasticity to enhance learning and to develop interventions to treat a range of disorders. A good review of this research is found in the article 'Harnessing neuroplasticity for clinical applications' (Cramer et al., 2011). Applications are being developed for rehabilitation after traumatic brain injury, improving cognitive functions impaired by various forms of mental illness, staving off cognitive decline accompanying the ageing process, general enhancement of cognitive functioning and for the treatment of various learning disorders.

Approaches to deal with dyslexia have been informed by neuroscience research. Imaging studies have found that the brains of dyslexics show different activation during reading tasks from the brains of proficient readers and that – after intensive remediation targeting phonological processing and, in some studies, both phonological and auditory processing – the children with dyslexia show increased activity in multiple brain areas, bringing brain activation in these regions closer to that seen in normal-reading children (Temple et al., 2003; Shaywitz et al., 2004; Meyler, Keller, Cherkassky, Gabrieli & Just, 2008). Studies demonstrate that children with dyslexia, through targeted training, can strengthen parts of the brain that enhance their ability to read. 'What we demonstrate is that we can change the way the brain works', says Marcel Just, director of the Center for Cognitive Brain Imaging at Carnegie Mellon (Meyler et al., 2008).

Neuroscience research has led to the development of programs designed with the intention of strengthening cognitive functions through stimulating neural processes to ultimately improve learning. Programs to tackle temporal acoustic processing – the ability of the brain to process rapidly presented speech sounds necessary for understanding speech and the acquisition of language, and which also plays a role in attaching sounds to symbols necessary for the reading process – have been shown to change regions of the brain related to the sound structure of language and to improve performance on measures of oral language ability and, in some studies, word blending, an aspect of phonological awareness (Merzenich, Jenkins, Johnston, Schreiner, Miller & Tallal, 1996; Temple et al., 2003; Heim, Keil, Choudhury, Friedman & Benasich, 2013).

Another program arising from research in the neuroscience laboratory is designed to deal with the construct of working memory – a term first used in the 1960s, referring to the capacity to hold and manipulate information in one's mind for brief periods of time (Pribram, Miller & Galanter, 1960; Baddeley, 2003). Working memory capacity has been found to be a strong predictor of future academic success (Alloway, 2009). Researchers have found that the ability to retain and manipulate information in working memory depends on a core neural circuit involving the frontal and parietal regions of the brain with other areas recruited as required depending on specific demands of the task: for example, verbal tasks will call on different regions from tasks that involve identifying objects (Rottschy et al., 2012). This same frontal–parietal network plays an important role in the control of attention and, as expected, working memory deficits are found in individuals with ADHD (Martinussen, Hayden, Hogg-Johnson & Tannock, 2005; Fassbender et al., 2011). Several studies have shown that working memory training leads to activation changes in the frontal–parietal network and improved performance on tasks requiring working memory and those involving attentional control (Klingberg et al., 2005; Klingberg, 2010) and that the gains in working memory were retained six months after the training (Holmes, Gathercole & Dunning, 2009; Holmes, Gathercole, Place, Dunning, Hilton & Elliott, 2010).

My work, begun in 1978, developed from two lines of research: research demonstrating neuroplasticity as a result of environmental enrichment (Rosenzweig) and research into the cognitive functions of regions of the brain (Luria).

The work of A. R. Luria (1966, 1970, 1972, 1973, 1977, 1980) established that different areas of the brain working together in a network are responsible for complex mental activities, such as reading or writing or numeracy. Each of these brain areas has a very specific and critical role to play in the learning process and a problem in the functioning of an area can affect a number of different learning processes.

In 1978 an article published in *Scientific American* confirmed, using brain imaging, that higher mental processes involve specific functional systems comprised of particular groups of brain areas working together (neural networks). This fact was confirmed by measuring the changes in blood flow to specific brain areas when a person was engaged in different tasks. An increase in blood flow directly relates to an increase in cortical activity. These researchers stated:

> *The analysis of cortical activation during reading illustrates that a complex task is carried out by several circumscribed cortical regions brought into action in a specific pattern … In general our results confirm a conclusion reached by the late A. R. Luria of Moscow State University on the basis of his neuropsychological analyses of patients with brain damage: 'Complex behavioral processes are in fact not localized but are distributed in the brain, and the contribution of each cortical zone to the entire functional system is very specific'. (Lassen, Ingvar & Skinhoj, 1978, p. 70)*

This led me to consider that a learning dysfunction might be the result of an area of the brain that is weaker in functioning than other areas in a network, thereby significantly impairing the learning activities of the network in which it is involved. Problems in learning and cognitive functioning can occur at many levels: in a brain area; in the connections between areas; and in the network.

The specific nature of the learning dysfunction depends upon the characteristic mental activities or operations of the particular area that is impaired and will be manifested in all the functional systems (neural networks) of which it is a component. For example, a problem in the area(s) responsible for motor planning in learning symbol sequences will affect learning motor plans in writing, reading, speaking and spelling.

Mark Rosenzweig (1966; Rosenzweig, Bennett & Diamond, 1972) investigated the effects of environmental enrichment on learning and the physiology of the brain, demonstrating neuroplasticity in rats. He found that the physiological changes in the brains of these rats were related to better learning: they performed better on maze tests. The conclusion: enriched stimulation led to physiological changes in the brain (neuroplasticity) that led to improvements in learning.

Luria's work led to the understanding and identification of the function of very specific cognitive areas critical to the learning process that became the basis of the Arrowsmith Program's cognitive exercises. Rosenzweig's contribution led to the idea that specific targeted cognitive programs might be able to exercise or stimulate and improve the functioning of these cognitive areas. In 1978, I created the first cognitive exercise to deal with my own severe learning problems and over time developed a range of cognitive exercises to tackle learning problems related to reasoning; thinking, planning and problem solving; visual memory for symbol patterns; lexical memory; memory for objects and faces; number sense and quantification; kinaesthetic perception; spatial reasoning; learning motor plans; and non-verbal thinking required for effective social interaction. I described this journey in my book, *The woman who changed her brain* (2012).

WHAT DO PROGRAMS DESIGNED TO TRAIN COGNITIVE FUNCTIONS HAVE IN COMMON?

UNDERLYING PRINCIPLES TO EVOKE NEUROPLASTIC CHANGE

The principles built into the program I began to create in 1978 are those that research now indicates are important factors to evoke positive brain change:

- design a task that places demands on a specific cognitive function (targeted/differential stimulation)
- start the level of task difficulty just above the level of current functioning and, as the individual attains mastery at that level, incrementally increase the difficulty (effortful processing; complexity; cognitive load)
- remove the support, wherever possible, of any areas that could compensate for the targeted weaker area of functioning (targeted/differential stimulation; effortful processing; novelty)
- build in performance mastery criteria that is rewarded (sustained attention; active engagement; reward effects on dopamine)
- repeated and prolonged practice.

Adele Diamond (2012) summed this up as 'hours and hours of practice trying to master what is just beyond your current level of competence and comfort (working in what Vygotsky, 1978, would call the "zone of proximal development")' (p. 337). This is Hebb's principle – neurons that fire together wire together – and the more they fire together, the stronger the connections (Sejnowski & Tesauro, 1989). 'If a network supporting a brain function is repeatedly stimulated through practice and training, it will become stronger, contributing to the optimization of that brain function' (Fernandez, 2013, p. 20).

GOAL OF COGNITIVE PROGRAMS

The goal of a cognitive program is not to teach content or the acquisition of skills. The goal is to change the underlying cognitive functions that are the basis of a wide range of learning processes that then allow for the learning of content and acquisition of skills. The premise of these cognitive programs is grounded in the principles of neuroplasticity – that the learner is not fixed, that the learner's brain is capable of meaningful and positive change – so that we do not have to compensate or work around cognitive problems but so that we can fundamentally change the learner's capacity to learn by creating cognitive programs that apply the principles listed above to evoke positive neuroplastic change.

TRANSFER: PROGRAM EFFECTS MUST TRANSLATE INTO REAL-WORLD CHANGE

A measure of the effectiveness of these programs is whether the change transfers to other areas of learning. For any of these changes to be meaningful, change must show up not just in brain-imaging studies or on better performance on the cognitive exercise, but critically as cognitive or behavioural change in the individual's real-world functioning.

Schmiedek, Lövden and Lindenberger made this point:

> *[the goal of these programs must be] the improvement of abilities, denoting gains in general mechanisms and capacities that carry the potential for improved performance across a wide range of tasks (cf. Thorndike, 1906). If training does not just improve task-specific skills but also broad cognitive abilities (cf. Carroll, 1993), then even small effects could lead to important benefits for individuals' everyday intellectual competence, as these improvements would generalize to all sorts of cognitive activities. (2010, p. 1)*

Given the complexity of the brain and its networks, we need to find multiple ways to measure these changes using behavioural observations from multiple sources (students, teachers, parents) to measure observable changes in real world functioning; measures of cognitive performance related to the functions being worked on; changes in rate of learning and acquisition of skills; changes in academic performance; longitudinal follow-up measures tracking academic, social and vocational progress; and brain imaging. A cautionary note has emerged from the research: brain change can take time to translate into measurable change on standardised academic test measures. This is probably explained by the fact that, once the cognitive capacity is in place, for academic skill acquisition to occur the student needs to be exposed to the material to now learn it and to fill in the learning gap that is present given the previous learning problems. Over time, this gap is closed as the student acquires the academic skills with the new learning capacities.

SUSTAINED CHANGE OVER TIME

Change in functioning seen at the end of a cognitive program must also be measured longitudinally – one, two, three and more years after the end of the program – to ensure the change in functioning is sustained and not just practice effect or the short-term temporary wiring changes noted by Lillard and Erisir (2011).

ARROWSMITH PROGRAM OUTCOME STUDIES

There have been a number of outcome studies conducted on students undergoing the Arrowsmith Program set of cognitive exercises. Each student is on his or her own program of cognitive exercises based on his or her profile of cognitive strengths and weaknesses as determined through an initial assessment process. Progress is measured monthly based on attaining benchmark goals in each of the cognitive programs and progress is measured annually through an assessment. The program is modified based on the student's measured improvement, with exercises being removed once certain criteria are met and other exercises being added as required, again based on the assessment.

There is a document, 'Academic skills and learning outcomes' (Arrowsmith Program, 2012), that summarises these studies; the studies are on the Arrowsmith Program website and a list appears at the end of this paper. These studies were conducted from 1997 to 2007, used different research designs and different measures, were both educational and cognitive, studied students at different schools and all showed positive learning outcomes. The Lancee (2005) study found a specificity of effect: improvement on a specific cognitive program showed related improvement on standardised tests that loaded on those cognitive functions.

NEXT STEPS IN RESEARCH

The next step, for Arrowsmith Program, is to partner with neuroscience researchers to start to explore what is happening in the brain as a result of the different cognitive exercises. Discussions have begun with researchers at several universities and our goal is to be underway designing this research in the next year.

NEUROEDUCATION – VISION FOR EDUCATION

Rather than change the way we teach, what is needed is to include cognitive programs as part of the curriculum so that students spend part of the day training their brains – the very organ they use to learn the curriculum and that they need when learning how to learn. Education becomes neuroeducation – the perfect marriage between neuroscience and education – and it will be about changing the capacity of the learner to learn as they learn. Through this partnership, the capacity to learn becomes as important as what is being taught.

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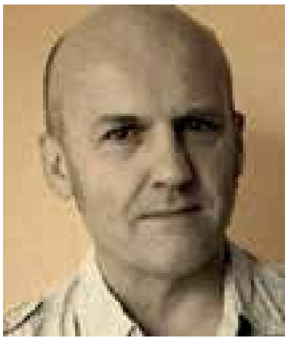
MINDS, BRAINS AND LEARNING GAMES



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

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

ABSTRACT

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

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

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

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

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

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

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

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

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

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

MAPPING THE POWER OF DIFFERENT PERSPECTIVES

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

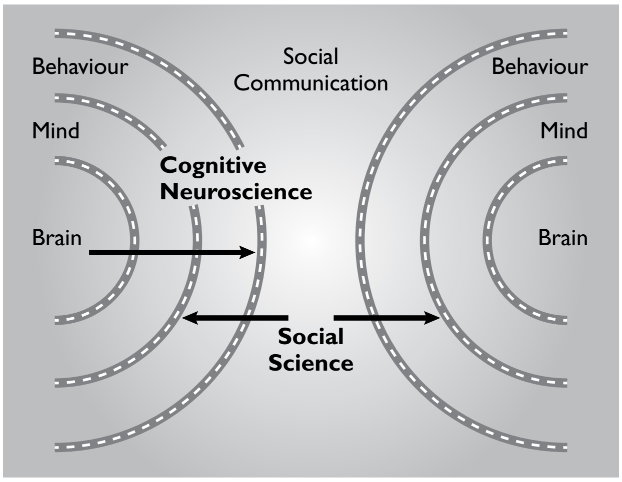


Figure 1 Two brain-mind-behaviour models (from P. A. Howard-Jones (2007), *Neuroscience and education: Issues and opportunities*, London, UK: Teaching and Learning Research Programme)

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

LEARNING GAMES

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

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

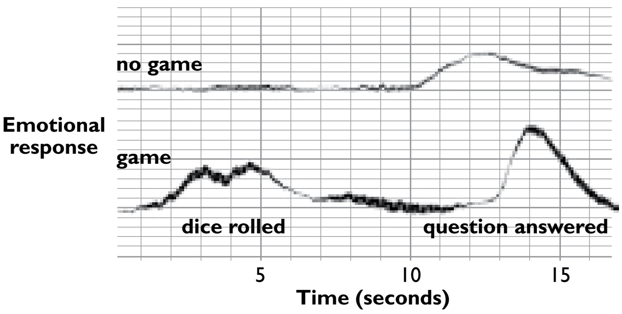


Figure 2 Emotional response and reward uncertainty

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

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

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

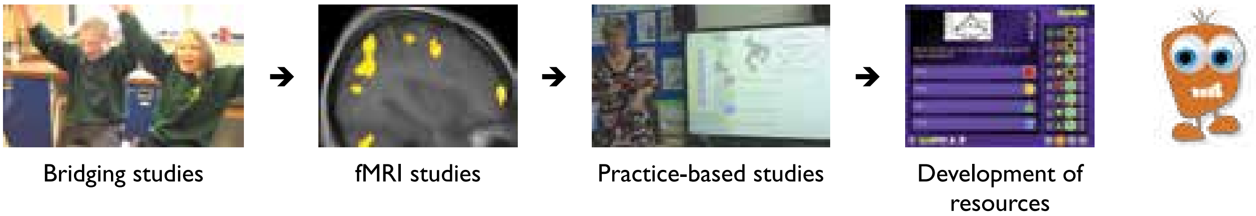


Figure 3 The NEnet investigation of learning games has involved bridging studies in the classroom and neuro-imaging studies to understand the competitive brain, leading to the development of free software that a teacher can use to teach any topic as a whole-class game ('Team Play' on http://www.zondle.com)

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

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

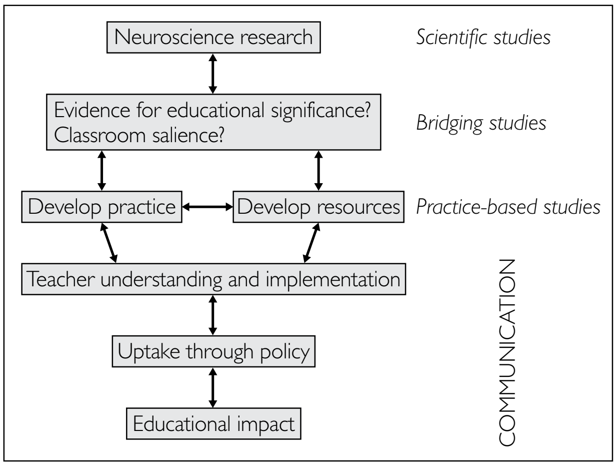
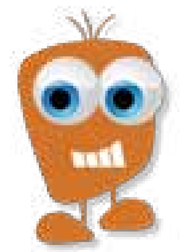


Figure 4 Effective pathways to success in neuroeducation

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

RESOURCES



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

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

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UNDERSTANDING LEARNING: LESSONS FOR LEARNING, TEACHING AND RESEARCH

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GREGORY YATES

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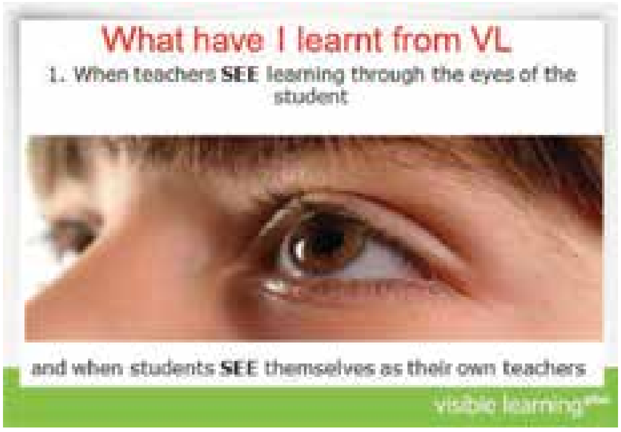
ABSTRACT

This presentation starts with the five major messages from Visible Learning, outlines a notion of 'learning', then develops seven fundamental principles of learning: learning involves time, energy, deliberate teaching, and effort; the structure and relations of learning; there are major limitations of the mind; the student as social animal; confidence as a multiplier; the need for maintenance and feedback; and identifying the major learning strategies. The new Science of Learning Research Centre is promoted as an opportunity for developing a 'heat map' of learning, for assessing, developing and enhancing learning – and for creating a powerful new narrative relating brain research to learning and teaching.

Over the past decades I have been trying to ascertain the major influences on student achievement. The three Visible Learning books have elaborated my findings – *Visible learning: A synthesis of over 800 meta-analyses in education* (Hattie, 2009), *Visible learning for teachers* (Hattie, 2012) and *International guide to student achievement* (Hattie & Anderman, 2013) – and the major theme in these books can be summed up by requesting teachers and school leaders to have the mindset 'Know thy impact'. This leads to closer attention on the impact of the adults on the learning of students, demands they seek evidence of student responses to their interventions, and begs the moral purpose question about the nature of worthwhile domains of understanding that the impact is meant to enhance. The claim can be expressed as shown in Figure 1.

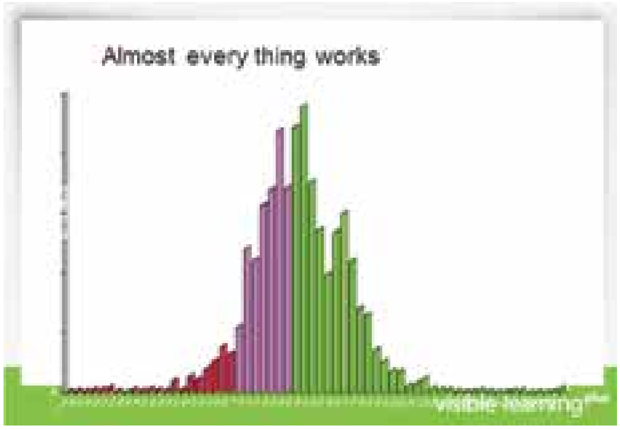
These are the 'Big Five' findings that follow from 'Know thy Impact':

- *All interventions are likely to work:* the question thus should be what is the magnitude of any intervention? Any intervention higher than the average effect (d = 0.40) is worth implementing.
- *The power of moving from what students know now towards success criteria:* the more students are aware, as



Source: Visible Learning Plus

Figure 1 Know thy impact



Source: Visible Learning Plus

Figure 2 All interventions are likely to work

they start a series of lessons, what success is expected to look like, then the more engaged they are in the challenge (provided it is a challenge as they may already know what it means to be successful, or the challenge may be too easy or too hard), and they more they are likely to enhance their achievements.

- *Errors are the essence of learning and they are to be welcomed as opportunities:* we go to lessons because we 'do not know' and thus errors, mistakes and not knowing are the key to all subsequent learning. Errors should be seen as opportunities to learn but to admit error requires high levels of trust (between student and teacher, and between student and student).
- *Feedback to teachers about their impact:* the most powerful person in most classrooms who relates to enhanced achievement is the teacher – the more teachers are open and seek feedback about their impact (relating to how many students they affect, which aspects of the lessons are being learnt, struggled with, and so on, where to go next).
- *The need for passion about, and to promote the language of learning*: it requires a passion to see the impact of one's teaching to maintain the energies, the mission and the attentions to student learning. It also requires a narrative about effort, learning, high expectations and avoiding a language of labels, ability and low expectations.

WHAT IS LEARNING?

The common feature in the above is a focus on 'learning' – although our current Australian community has an obsession about 'achievement', 'standards' and 'ability'. The latter lead to policies that favour those with higher achievement, those above the standards and those with much ability. This obsession is more negative about those with lower achievement, those not above the standards, and those with lower ability. This has led to claims about schools or students from low socioeconomic areas not being successful, and schools or students in leafy suburbs being successful, and this has muddied the waters about the nature of success in schools. As has been documented elsewhere (Griffin, 2013), Australia is falling backwards in the world comparisons and most of this 'backwards' movement is a function of the top 20–30 per cent of students not gaining as much as they did 10–20 years ago. Partly, this is because of the attention to the lower achievers, lower socioeconomic areas and the claims that they are 'not above the standards' and thus we have avoided a focus on the learning of the top 20–30 per cent. Indeed, there is much evidence that Australian teachers are more effective with the below-average students in terms of adding value to their prior achievement and enhancing their learning, and not so effective with those students above the average (Griffin, 2013). There is much power in getting the narrative correct.

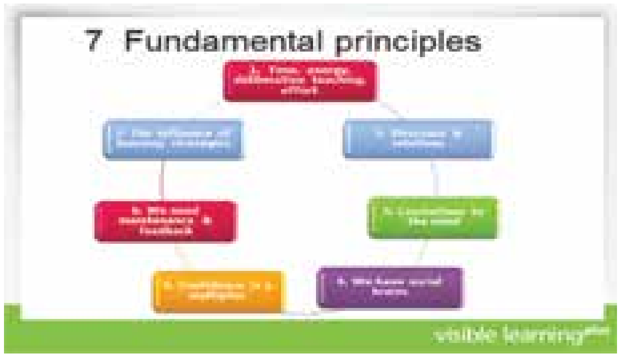
A major argument in this discussion is that there should be more attention to the narrative of 'learning', as it is via developing 'learning' for all students that there will be subsequent effects on 'achievement'. While there are many definitions of 'learning', the one that is the basis for this presentation is that learning is the process of developing sufficient surface knowledge to then move to deep or conceptual understanding. There are many influences in the Visible Learning work that indicate the importance of this notion of learning (see Table 1).

Table 1 Influences that indicate the importance of the notion of learning as moving from surface to deep knowledge

Rank	Influence	Effect size
1	Student expectations	1.44
7	Classroom discussion/listening to learning	0.82
10	Feedback	0.75
11	Reciprocal learning – questioning, clarifying, summarising, predicting	0.74
12	Teacher–student relationships	0.72
13	Spaced v. mass practice	0.71
14	Metacognitive strategies	0.69
21	Self-verbalisation and self-questioning	0.64
22	Study skills	0.63
23	Teaching strategies	0.62
24	Problem-solving teaching	0.61
27	Concept mapping	0.60
32	Worked examples	0.57
48	Goals	0.50
54	Concentration/persistence/engagement	0.48

Source: Visible Learning Plus

SEVEN FUNDAMENTAL PRINCIPLES



Source: Visible Learning Plus

Figure 3 Seven fundamental principles

PRINCIPLE 1: LEARNING INVOLVES TIME, ENERGY, DELIBERATE TEACHING AND EFFORT

Substantial investments of time, energy, deliberate teaching and personal effort are required to develop mastery in all knowledge domains. Intelligence, ability and talent are not enough. Consider a study by Clark and Linn (2003) in which the same science eighth-grade curriculum was taught in four different ways: either as a full 12-week semester topic, or in streamlined (cut-down) form in either nine-week, six-week or three-week versions. The same four topics were covered, but the amount of time devoted to the four units of work was dramatically reduced. Assessments took the form of both multiple-choice and written tests. The results were startling. The reduced time allocations barely made any impact on the multiple-choice tests. But students who had to cover the content in reduced time were unable to pass the written tests that assessed the depth of understanding. For instance, students who covered the content in three weeks scored around 25 per cent on the written sections, despite scoring 90 per cent on the multiple-choice test. Students who had studied the full version scored 90 per cent on multiple choice and 67 per cent on written sections.

It is not time, but particular uses of time and timing. And this relates specifically to investments in learning. The greatest predictor is engaged time and academic learning time, particularly for low-achieving students. But simply spending more time on an activity does not necessarily lead to skill improvement unless there is a deliberate effort to improve student performance, such as specific teaching to the skill, making the success criteria explicit or feedback to reduce the gap between where the student is and the success criteria. It is deliberate practice.

Note, as an aside, the number of intended instruction hours in primary and high schools across 34 countries (see Figure 4) – and the correlation with PISA: reading is 0.20, maths 0.32 and science 0.35. Longer is not necessarily better.

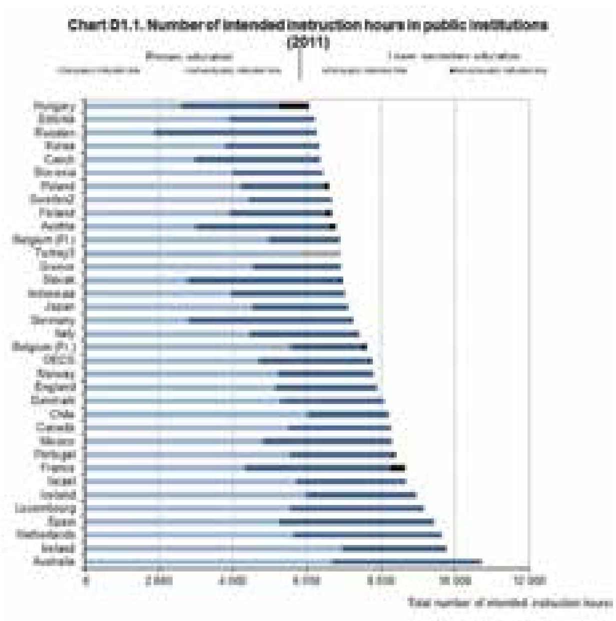


Figure 4 Number of intended instruction hours in public institutions

The key idea behind deliberate practice is that the time devoted to training tasks needs to be such that a person can identify and achieve mindfully and sequentially. Instead of being haphazard or recreational, this form of practice is highly structured. Typically, practice schedules are achieved under supervision of a teacher or coach. Performers are presented with tasks that are initially outside current performance levels but that can be mastered within hours by focusing on critical aspects and refining technique though repetition and feedback. In essence, there is always an intended cognitive or psychomotor skill targeted and this is assessed though objective means. Immediate short-term goals and adaptive corrective feedback become major components inherent in this process.

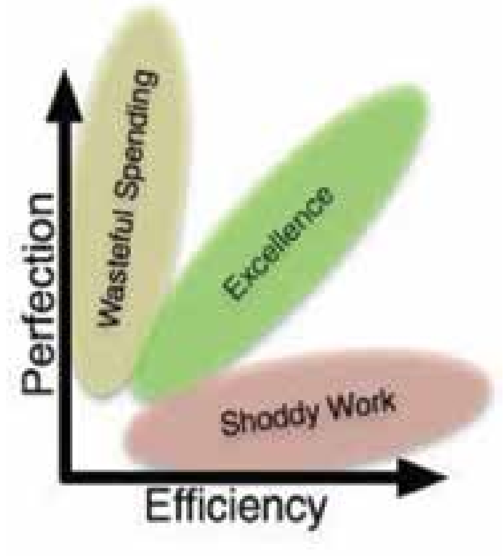


Figure 5 Perfection v. efficiency

Where is the concept of efficiency in schooling? Imagine two high school teachers teaching the same concepts to groups of similar students. If one teacher manages to have all students learn these concepts in half the time of the other teacher – where is the reward? The problem is that this teacher still has the same time and now has to find something to do with the students in the other half of the time. Often they cannot go too fast and then impinge on the next level of the curriculum as they can disturb the next teacher's expectations and timetabling about what is supposed to happen. At best they can provide enrichment – and such spreading sideways has low effect-sizes on assisting students to learn new challenges. When I look at many accountability systems, it is rare to find anyone grappling with introducing efficiency as a desirable attribute of systems (but see Colorado's model).

When we ask teachers what they mean by 'challenge', they often refer to the nature of the material: this text is challenging but this one is not; this problem is challenging but this one is not. But some students do not then engage with the challenge of the text and thus do not see it similarly! When you ask students, they say challenge is 'when their head hurts'. So here is a problem. It requires much effort and it is tiring to overindulge in learning.

Since the beginnings of psychology there have been explanations of how we think at least two levels. William James (1890/2007) distinguished between associative and deep thinking; others have distinguished systems, one that is classical and operant conditioning and a second system that is the more conscious aspects of our thinking mind. System 1 is fast and responds with immediacy; System 2 entails using time to 'stop, look, listen, and focus' (Stanovich, 1999). More recently Daniel Kahneman (2011) wrote about the two systems he distinguished as 'thinking slow' and 'thinking fast'. Slow thinking is System 2, which requires deep, challenging and sometimes 'hurting' thinking. Fast thinking is System 1, which rapidly calls on knowledge to be used in thinking slow. The more we make learning automatic (like learning the times tables) the easier is it for us to devote our cognitive resources to System 2 deeper tasks (such as using the times tables to problem solve).

For those who struggle at school there is a double whammy – they do not have as much 'fast' automatic System 1 knowledge, thus when asked to do System 2 (slow thinking) they have to not only recall and understand the times tables then have to apply it to the problems. The more able students only need to devote their thinking resources to System 2, slow thinking.

Too often we then label these students with lower System 1 thinking as struggling, not able, and so on, and the vicious cycle continues The art of teaching is to ensure that the task is appropriate – for example, give the struggling students the System 1 knowledge so they can devote the cognitive resources to tackle the System 2 problem and thus make them more equal to the brighter students who have better System 1 capacities.

So the message for Principle 1 is extensive engagement in relevant practice activities at an appropriate and challenging level, enabling successive refinement, with room to make and correct errors, and lots of feedback. It is time devoted to conscious monitoring, time that requires concentration and persistent such that there is stretching to take on new challenges until these challenges becomes automatic. It is introducing efficiency into the lexicon of teachers and learning. Further, it is being aware of what cognitive resources we need to bring to a task to 'make our head hurt', knowing that we can only do this thinking slow for short durations, that it is built on high access to thinking fast (more automatic) knowing and structuring tasks to allow not only for the thinking capabilities of the student but also in being specific in the success criteria as to what is required.

PRINCIPLE 2: STRUCTURE AND RELATIONS

Luria (1976) was one the pioneers of relating the brain structures and functions to human learning. He developed a tripartite model of learning including simultaneous thinking, successive thinking, and planning and executive functioning (see Naglieri, Das & Goldstein, 2013).

Successive processing involves information that is linearly organised and integrated into a chain-like profession (parsing from the particulars to the whole) and simultaneous processing involves seeing the whole and then parsing into the particulars. Planning, executive control, develops later (he argued about age 9–12 years, which compares to Piaget's move from operational to formal operational thinking) and is responsible for regulation, conscious impulse control, self-monitoring, planning and executive regulation. For example, many whole language advocates base their claims on simultaneous thinking (if the students see the whole, they can then appreciate the details), whereas phonics proponents base their claims on successive thinking (if the students understand the specific parts, they can then form whole words or texts). Of course, it is not that simple, but we do note the effect-size from the whole language is 0.06 and phonics is 0.54. I also note a good model that shows that is not that simple (see Figure 6).

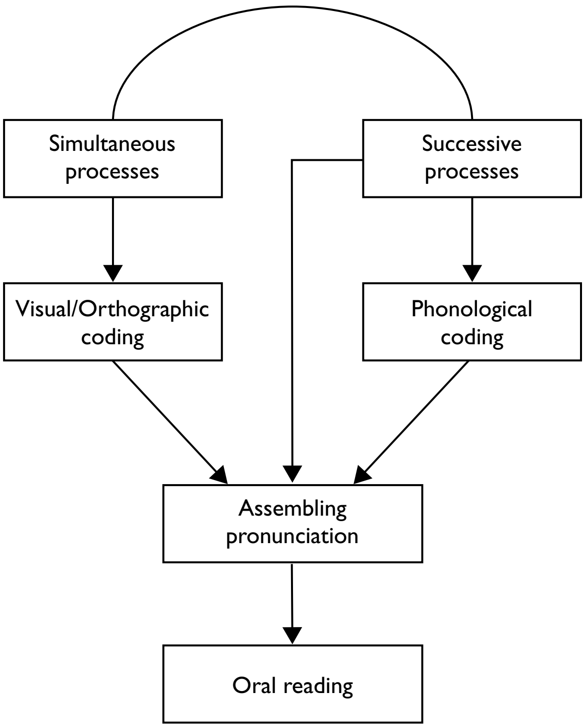


Figure 6 Reading is not simple

There is a strong claim that our brains start more in the simultaneous mode as dominant – we see a work and make inferences and interpretations – often through play and early experiences with parents, siblings and peers. Then along comes school, and in particular reading, which primarily relies on skills in successive thinking. As Scribner and Cole (1900) noted, reading then serves two functions: it not only teaches students how to think successfully, it is also a useful skill to then be able to read so we can learn many other subjects. But so often teachers see it only in terms of the latter and fail to realise they are teaching a specific set of learning skills – how to think serially. For many students who have not picked up this skill prior to coming to school this is a double whammy – they struggle to learn to think serially and now have difficulties in reading that prevent them then 'reading to learn' other subjects.

In many ways the computer interfaces of today demand more simultaneous thinking and many of the successive thinking skills we have are not as relevant to this interface. Maybe this is why some teachers struggle to incorporate technology into their teaching – they are over-engaged with and over-value developing successive thinking. Perhaps in the beginning there was simultaneous thinking, along came the printing press such that societies then valued successive thinking, and with technology we are reverting to value simultaneous thinking – and the world of schools has not kept up. Of course, it would be wonderful if we had both, although for me (Hattie), I know that I am so much better at successive than simultaneous and have learned to cope with simultaneous stimuli by working out how to successively process – but this is much 'slow' thinking.

Now, let us place these notions of 'fast' and 'slow' and Luria's thinking into one model (see Figure 7). The SOLO model was developed by John Biggs and Kevin Collis (1982) and has four levels: one idea, many ideas, relate ideas and extend ideas. The first two relate to surface knowing and the latter two to deep knowing. We have used this model in developing test items, scoring rubrics, classroom observation, developing teaching lessons, analysing progress and for understanding learning. The model highlights the importance of knowing something (the first two steps) before thinking about it. Too many innovations in education value the deep and forget it is based on the surface.

Source: Visual Learning Plus

Figure 7 The SOLO model

One of the hardest things to accomplish in learning is transfer of understanding. This is because deep understanding is so embedded in the knowing of much surface information. This is why many programs like enquiry-based teaching (0.31) and problem-based learning (0.16) have low effects, as they are too often introduced outside the context of knowing many ideas, or introduced as some kind of generic skills development that can then be applied across content domains. (Note, for example, problem-based learning is much more successful in the fourth and later years of medical school but not in the first year of courses).

Certainly one of the features of high-impact passionate teachers is their proficiency to move students from surface to deep knowledge. In a study of National Board Certified (NBC) teachers, compared to similarly experienced but non-NBC teachers, we found that the greatest difference related to the SOLO taxonomy (Smith, Baker, Hattie & Bond, 2008). We collected artefacts of student work, and developed scripts of the lesson plans and had these independently coded as to evidence of surface or deep knowledge. In the classes of the expert teachers, 75 per cent of the artefacts were at the deep level and 25 per cent at the surface, whereas in the experienced teachers' classes, 25 per cent of the artefacts were at the surface level and 75 per cent at the deep level. Expert teachers know how to move students from surface to deep much more effectively than non-experts.

PRINCIPLE 3: LIMITATIONS OF THE MIND

Source: Visual Learning Plus

Figure 8 Limitations of the mind

Dan Willingham (2009) has advanced the thesis that the human brain does not naturally want to think about matters we normally deal with in schools. This is because school thinking requires much effort, the realisation of much brain resources and allocation of personal energies, high levels of confidence (particularly in the face of making errors and the face issues of 'not knowing'), high levels of uncertainty and many unknowns, and thinking uses up many resources. To resist an invitation to think is not necessarily an indication of laziness. It could reflect a decision to be economical, cautious or even prudent with our personal resources. It is much easier to conserve energy and avoid initiating actions when outcomes are uncertain. If you have had many opportunities to not realise learning when asked to expend the energy it helps confirm the belief that it is not a good use of thinking (e.g. thinking slowly) next time so it is easier to resist and not engage. Indeed many of us are quite risk averse, so why should children also not be so?

Plus there is mental availability – there are issues of ease of access to surface knowledge to then manipulate, relate and extend; there are constraints of working memory as how much we can hold in memory and work with at the one time; there are knowledge gaps that are revealed when thinking that need attention before relating (we may expend energy to close knowledge gaps but give up if they are knowledge chasms); it is easier to rely on memory than thinking (and our memory for ideas may be limited in some domains); and most of us have beliefs about knowledge (indeed I survive very well with beliefs about how cars move and know next to nothing).

John Sweller (2008) has been most instrumental in outlining the limitations of our cognitive load, and showing ways to optimise learning within our load limitations. He noted that there is intrinsic cognitive load that is fixed by the nature of the task; extraneous cognitive load imposed by the learning conditions and instructional context; and the personal cognitive load, which is the limitations of how much can be processed by a particular individual. Obviously balancing these loads is the critical aim of instruction. For example, one way to assist students to solve a maths problem is to reduce the load by giving them the answer so then they concentrate on the process. Providing students with worked examples is a powerful method (note the effect size of 0.57 by providing a group with a worked example compared to another group learning the same material without a worked example). Similarly the 'flipped classroom' invites students to overview the vocabulary and main ideas before then immersing oneself in learning these ideas and the relations between them. Having pictures and words, having prompts and questions very adjacent, avoids using cognitive resources to flip between ideas; getting rid of redundant material stops expending energy of what matters less (clarity outweighs elaboration); hearing other students thinking about the material as well as the teacher greatly enhances learning (we are indeed social learning animals); and having multiple opportunities to learn the material (particularly over time) are all other ways to reduce cognitive load – such that the student can think slow about what really matters in the learning.

PRINCIPLE 4: WE ARE SOCIAL ANIMALS IN REACTING TO OTHERS, LEARNING FROM OTHERS

We learn from social examples: watching, doing, deliberative instruction and feedback from other people. Similarly, much *information assimilated through personal discovery can be shallow, insecure and incomplete*. Consider the following five teaching principles that seem intrinsic to human evaluation and species survival (Csibra & Gergely, 2006):

- the cooperativity principle: there will be adults around who will transmit relevant knowledge even at some cost to themselves
- the principle of ostension: an adult signals to the child that an act is shown for the child's benefit and not the benefit of the adult teacher
- the principle of relevance: both child and adult teacher recognise the goal-directed nature of the learning situation, that the knowledge communicated is novel, and would not be figured out by the child unaided
- the omniscience principle: mature members of the community store knowledge in themselves that they can manifest anytime even when they are not in any need to use the knowledge themselves
- the public knowledge principle: the knowledge transmitted is public, shared and universal. The classic example here is language. Vocalisations and words used by one adult individual are not unique to that individual.

We spend much time mimicking and watching others; indeed we are very much social chameleons. Graeme Nuthall (2007) has written extensively of the power of social relations in the classroom and how students learn a tremendous amount by mimicking other students, by watching and listening to how they interpret what teachers say and do, and his book was appropriately entitled *The hidden lives of learners*, due to how much is actually hidden from the teacher who stands up front, dictates the lesson flow, talks the majority of the day, and then reflects on the 20 per cent (maximum) that the students see and hear. It is why I have entitled my work 'visible learning' to highlight the importance of making the learning visible. It is probably why mirror neurons have so much to say about how we learn.

Mirror neuron theory suggests that whenever humans interact within the same physical space, the brain of the individual who is observing will neurologically 'mirror' the person they are watching. A good deal of research into this effect then followed to the point where a general conclusion appears possible: *the same cortical circuits that are implicated in executing an action respond also when observing someone else executing that action*. Although research with human beings cannot be carried out with the same level of precision possible with animal subjects, many studies using magnetic imaging techniques show critical areas of the brain are highly active when people watch and interpret other human beings. The watching seems particularly important in reinforcing prior learning, or from listening to teachers and reading material.

PRINCIPLE 5: CONFIDENCE IS A MULTIPLIER

We need a certain amount of confidence that we can learn a task before we are prepared to exert mental energies in to learning, and to facing the risk that we may fail. This is why in Visible Learning there is so much emphasis on success criteria, as they can indicate to the student what success looks like and the student (often with help) can estimate how far away from success he or she is, the amount of energy needed to attain success, and to be more focused on attending to the tasks that lead to the success. So often classrooms ask students to 'engage' and such a low-level success criteria is often endless (when they have succeeded in 'engaging' they are asked to do more 'engaging'). Instead we need to invoke the 'Goldilocks' principle: the success criteria cannot be too easy and not too hard. Similarly some of the teaching tasks are to inspire confidence, to provide the safety nets, and to help in calibration and efficacy of learning judgements – and certainly social interactions with others are crucial in the developing these competencies.

Figure 9 Confidence is a multiplier

PRINCIPLE 6: WE NEED MAINTENANCE AND FEEDBACK

We require high levels of maintenance in learning and thus the ability of teachers to diagnose where the student is relative to the criteria of success is critical. This is where notions such as assessment *for* learning, of assessment *for* teachers, student assessment capabilities are all invoked – the aim of using assessment to help understand where in the progression the student is such that appropriate interventions can take place. This leads to many critical learning notions:

- the importance of multiple opportunities to learn: most of us need three to four different opportunities to learn before we actually learn and remember knowledge

- this is why we need the proverbial 10 000 hours to become experts, as it requires high levels of deliberate practice, over learning, attending to the many potentially valuable relations (and students spend about 15 000 hours in school from ages 5 to 16, so we do have this time)
- maintenance is optimised with spaced versus massed practice ($d = 0.71$).

This emphasis on maintenance implies a worthwhile model for teaching not based on the typical models of constructivism, enquiry learning, direct instruction, eclecticism and so on but on the notion that teachers are to DIE for – diagnosis, intervention and evaluation. The optimal model is when teachers have high-level skills in diagnosing where on the learning progression a student is, having multiple interventions in their tool kit then to optimise the best teaching relative to that diagnosis, and constantly evaluating their (the teacher's) impact on the learning and where needed to alter their behaviour, their interventions and their materials to optimise student learning.

We have for too long seen the maintenance of learning embedded in the student and, of course, this is where we want it – but it so often does not start there: it starts with deliberate teaching. This is why we have spent so much time developing assessment tools for teachers to help them know their impact (e.g. e-asTTle: Hattie, Brown & Keegan, 2005), why we want teachers to assist students to become assessment savvy to help in their own diagnosis, response to intervention and evaluation of learning, and why we see the 'teacher as evaluator of their impact' as central to the Visible Learning messages.

A key aspect of maintenance is feedback, as it is what happens *after* instruction. The meta-analyses relating to feedback show very high values ($d = 0.75$) but it is also among the most variable of effects. We have endeavoured to develop a model of feedback based on three critical feedback questions that work at three different levels, as shown in Figure 10 (Hattie & Timperley, 2007).

Source: Visual Learning Laboratories

Figure 10 The three-level feedback model

This is a topic for a whole session, so let me just provide some highlights here.

- The three levels shown in Figure 10 correspond to the SOLO taxonomy: *task* is akin to surface, *process* to the jump from surface to deep and *self-regulation* is indeed deep learning. Thus the nature of feedback that is most powerful differs as the student moves from surface to deep.
- When we ask teachers what feedback means they typically focus on 'Where am I going' and 'How am I going'. They emphasise the 'past', typically providing feedback in terms of comments, clarifications, criticism, confirmation, content development and corrections. But when you ask students, they are emphatic – it is what helps them know 'Where to next?' and in our analyses of feedback (written and verbal) that is less frequent in classrooms (other than procedure directions to complete this, do that).
- There is a crucial distinction between feedback given (there is often a lot given by teachers in a day) to feedback received (typically can be measured in seconds per student). Much feedback given (especially to whole classes) is rarely received. Thus the need to focus on how students understand the feedback given, what they interpret from this feedback, and what they then use to progress.

- Among the most powerful notions is that when the feedback to the teacher is maximised about their impact on students, this has the greatest beneficial effects for the student, as it is then teachers are adaptive in their interventions, have a more effective sense of the magnitude of the influence they are having, and the prevalence of their impact is shown to them in terms of how many students are 'learning'.
- One of the most powerful ways for teachers to 'hear' their impact is via classroom dialogue (d = 0.82). This is more rare than many expect (for example, over three months in the Gates MET study (Joe, Tocci & Holtzman, 2012), about 60 per cent of maths classrooms in the USA did not have a single classroom discussion), they are not easy to set up to maximise return (I have PhD students working on the efficiency of setting up dialogue), and there seems so much reinforcement value in students hearing other students thinking aloud ('Come on down mirror neurons'!).
- We need to be more attentive to observing students learning in classrooms and less attentive to how teachers teach. Watch the students not the teacher; watch the impact of the teacher on students not the teaching methods of the teacher.

PRINCIPLE 7: LEARNING STRATEGIES

There has been a long history of searching for the best learning strategies that students can learn to benefit their learning. In this last section, these are outlined and a direction offered to better understand the optimal learning strategies, understand the moderators or conditions under which various learning strategies are best invoked, and to emphasis the notion that these strategies can be taught. At the moment, about 5 per cent of classroom time is spent teaching skills and strategies and this seems minimal if learning to learn is so powerful. There is also a tendency by students (indeed by all us) to overuse the few strategies that seemed to have worked for us in the past – and often this leads to reinforcing non-optimal strategies. Sometimes we need to be taught to unlearn some strategies and replace them – and this is a worthwhile aim of schooling.

The first message is that generic learning strategies can be used for surface-level knowledge but, to attain deeper knowing, it needs to be underrated within the content domain. Consider, for example, the SOLO taxonomy: strategies such a mnemonics, rote learning and memorisation can be undertaken with learning an idea or ideas but have much less impact for relating and extending ideas. Hattie, Biggs and Purdie (1996) completed a meta-analysis of 279 effects from 51 studies on the effects of learning strategies and found that lower level strategies have a reasonably high effect on surface learning but much lower effects on deeper learning. When the thing to be learned is near (immediate recall, soon after learning, reproductive) strategies out of context have a higher effect than when it is far (long-term recall, transformational) when it needs to be accomplished within the subject domain.

The effectiveness, particularly for learning deeper understanding, may be more subject-specific. De Boer, Donker-Bergstra, Daniel, Kostons and Korpershoek (2013) used 95 interventions from 55 studies and found that the influences of strategies are higher in writing (1.25), science (0.730), maths (0.66) and lowest in reading comprehension (0.36). The most effective combination of strategy instructions included a combination of 'general metacognitive knowledge', the metacognitive strategy 'planning and prediction' and the motivational strategy 'task value' or valuing the task to enhance student performance the most effectively. Thus:

> *teaching students skills such as determining when, why and how to use learning strategies, how to plan a learning task, and explaining the relevance and importance of a task (so that they see the importance of what they are doing) are therefore important aspects of self-regulated learning interventions. (De Boer et al., 2013, p. 59)*

Valuing the task was the single greatest effect and this entailed not only the degree to which the task is considered as relevant, important and worthwhile – the development of a positive style of attribution, which enhances the student's self-efficacy – but also being aware of what success in the task looks like and why it is powerful for further learning (including the student's belief in his or her ability to successfully complete the task). In maths, elaboration, or connections to new material was more effective and this emphasises knowing student's prior or current understanding and then connecting the student to 'where to next'. The bottom line, however, is that it is a combination of strategies ($d = 1.32$), not a single one-at-a-time strategy. There is also a criticalness about students knowing what success looks like before undertaking the task and giving feedback that relates to 'where to next' that is the key to then gaining the value out of learning strategies.

Dunlosky, Rawson, Marsh, Nathan and Willingham (2013) completed probably the most comprehensive review of 10 strategies.

- practice testing: self-testing or taking practice tests over to-be-learned material
- distributed practice: implementing a schedule of practice that spreads out study activities over time
- elaborative interrogation: generating an explanation for why an explicitly stated fact or concept is true
- self-explanation: explaining how new information is related to known information, or explaining steps taken during problem solving
- interleaved practice: implementing a schedule of practice that mixes different kinds of problems, or a study schedule that mixes different kinds of material, within a single study session
- summarisation: writing summaries (of various lengths) of to-be-learned texts
- highlighting/underlining: marking potentially important portions of to-be-learned materials while reading
- keyword mnemonic: using keywords and mental imagery to associate verbal materials
- imagery for text: attempting to form mental images of text materials while reading or listening

Table 2 How generalised were the effects?

Materials	Learning conditions	Student characteristics	Criterion tasks
Vocabulary	Amount of practice	Age	Cued recall
Translations	Open v. closed book practice	Prior domain knowledge	Free recall
Lecture content	Reading v. listening	Working memory capacity	Recognition
Science definitions	Incidental v. intentional learning	Verbal ability	Problem solving
Narrative tests	Direct instruction	Interests	Argument development
Expository tests	Discovery learning	Fluid intelligence	Essay writing
Mathematical concepts	Rereading lags	Motivation	Creation of portfolios
Maps	Kind of practice tests	Prior achievement	Achievement tests
Diagrams	Group v. individual learning	Self-efficacy	Classroom quizzes

Source: Visual Learning Plus

- rereading: restudying text material again after an initial reading.

They found two strategies that had highest effects – practice testing and distributed practice (spaced v. massed); three with moderate effects – elaborative interrogation, self-explanation, interleaved practice; and the others low effects. They also found no major moderators to these conclusions (see Table 2).

Finally, Lavery (2008) completed a meta-analysis and found highest effects for organising and transforming, self-consequences, self-instruction/verbalisation and self-evaluation (see Table 3).

The bottom line is that low-level strategies more effective for near or surface-level learning, but strategies must be taught in the context of the subject to attain deep-level knowledge; and the effectiveness of strategies for depth is likely to vary across subjects. Strategies or study programs that are taught out of context (like Feuerstein and Arrowsmith) may led to gains for surface knowing (and this is indeed most worthwhile) but are unlikely to have as much effect in leading to deeper understanding. So, we need to know when to play 'em and know when to hold 'em.

These studies also reinforce the power of six big ideas:

- developing student assessment capabilities, being involved in planning and prediction (for example, knowing success criteria), and seeing the value of the task
- allowing students to 'hear themselves think' (self-verbalisation, self-explanation, self-consequences, self-instruction, self-evaluation) – that is, participating in becoming self-teachers

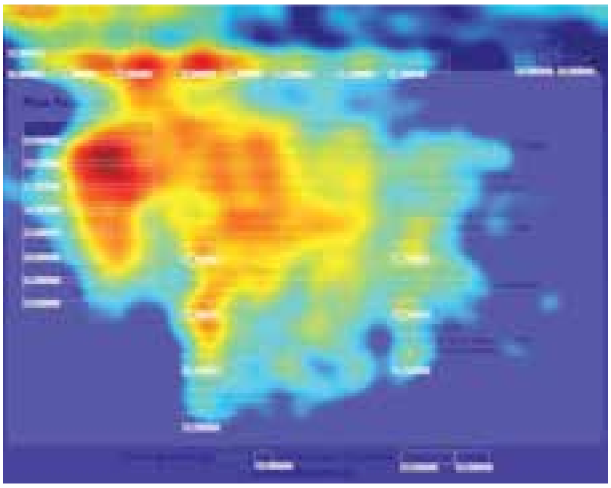
Table 3 Learning strategies sorted by effect size

Strategy	Example	Effect size
Organising and transforming	Making an outline before writing a paper	0.85
Self-consequences	Putting off pleasurable events until work is completed	0.70
Self-instruction	Self-verbalising the steps to complete a given task	0.62
Self-evaluation	Checking work before handing in to a teacher	0.62
Help seeking	Using a study partner	0.60
Keeping records	Recording of information related to study tasks	0.59
Rehearsing and memorising	Writing a mathematics formula down until it is remembered	0.57
Goal setting/planning	Making lists to accomplish during studying	0.49
Reviewing records	Reviewing class textbook before going to lecture	0.49
Self-monitoring	Observing and tracking one's own performance and outcomes	0.45
Task strategies	Creating mnemonics to remember facts	0.45
Imagery	Creating or recalling vivid mental images to assist learning	0.44
Time management	Scheduling daily study and homework time	0.44
Environmental restructuring	Efforts to select or arrange the physical setting to make learning easier	0.22

Source: Lavery (2005)

- participating in deliberative practice (not just rote learning and lots of practice) that is distributed or spaced
- being given and seeking feedback particular related to then valuing the task and seeing the benefits and effects of learning the ideas
- teaching relations between ideas – organising and transforming (seeing the higher level connections)
- knowing many power strategies and then knowing when, why and how to use them –knowing what to do when you do not know what to do.

CONCLUSIONS



There is much to do, and one of the wonderful opportunities is the establishment of the Science of Learning Research Centre between the University of Melbourne, ACER and the University of Queensland. We have a healthy agenda and it is exciting that the agenda of this conference is to be that of many of our academic lives for the next four years. The three themes of the Centre are developing learning, understanding learning and assessing learning. Let me conclude with two of my wishes for the centre.

First, I would like to see a prioritisation of attention to the most critical learning strategies and not a shotgun approach at any that just seem interesting or easy to measure. Then would it not be wonderful to develop a 'heat map' of learning in a classroom such that teachers can better understand where learning is occurring, as opposed to coasting, distraction, or confusion?

This means we need better measurement of learning. I would argue we have excellent, indeed an over-saturation of, measurement of achievement and adding more seems wasteful. But we have few measures of learning, and certainly few measures of learning not based on self-report scales. To develop scenarios, to develop vignettes, to develop real-time simulations where a student's learning strategies can be understood, to know then how able a student is to retrieve, apply and learn from various strategies, how the student switches between strategies, and how to optimise the use of the strategies would be powerful. Then we may be better prepared to *teach* students learning strategies and how and when to use them; this may lead to changing the current narrative from why students cannot learn and hence prescribing drugs (for example, Ritalin), labelling (for example, autism, Asperger's), and actually change students' learning strategies to maximise learning and create opportunities for them to become their own teachers. Therein is one aim.

Second, we cannot promise to find the brain correlates of learning within the next four years. I think we know a lot about the brain and learning, but know so little about how to use such information in a classroom. We are spoilt with silly claims about the brain and the neuro-trash and absurd claims are aplenty (see della Chiesa, Cristoph & Hinton, 2009; Lilienfeld, Lynn, Ruscio & Beyerstein, 2010). Consider four examples:

- It could be the case that the music training during childhood facilitates certain aspects of cognitive development in non-musical areas (the jury is still out). *But* this knowledge is *not helped* by overblown fallacious claims that listening to Mozart's sonatas stimulates dormant neurones and so promotes a student's intelligence and ability to study.

- Individuals are dramatically different in how they respond to information, how they recognise patterns, and in the knowledge and strategies they bring into a learning situation. *But* this knowledge is *not helped* by overblown claims that learners come with distinctive styles of learning that affect how they actually do learn.
- Young people are accustomed to using modern technologies and highly powered software to produce impressive PowerPoint displays. *But* this knowledge is *not helped* by overblown claims they form a new variant species called digital natives.
- It is the case that learning necessarily involves neurological correlates. *But* this knowledge is *not helped* by overblown claims that school learning has to follow brain-based learning principles. (Brain-based learning is as meaningful as leg-based walking or stomach-based digestion.)

In each instance, the validity of the genuine knowledge claim is countermanded by advocates who go too far. How do we know what is valid and what is overblown? That is what science will do for us: it brings constraint into the business of claiming knowledge. Science demands that claims reflect a validly generated database of evidence. And this is how it has to work for education. Reality is harsh: many 'soft options' thrive, have their moment in the sun and whither on the vine.

Thus the second aim for the science of learning over the next four years is to create a better narrative about the implications of brain research for learning: one based on the dynamics and flow of information and learning and not structural claims (right brain, left brain, the brain is a muscle, and so on); one that allows all of use to converse in a language that makes a difference to our teaching and learning. It is an exciting few years ahead.

Throughout this discussion the words 'brain' and 'neuroscience' have barely been mentioned. This is not because these are unimportant, to the contrary. It is because the current dialogue is overblown in too many false claims and a major mission of the Science of Learning Research Centre is to identify, research and understand effective teaching and learning practices in the light of current knowledge about basic learning processes and factors that influence successful human learning.

All the parts of this presentation are expanded in our forthcoming book: *Visible learning and the science of how we learn*.

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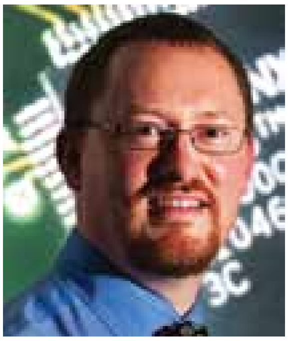
CONCURRENT PAPERS

WHEN THE EDUCATIONAL NEUROSCIENCE MEETS THE AUSTRALIAN CURRICULUM: A STRATEGIC APPROACH TO TEACHING AND LEARNING



MARTIN WESTWELL

Flinders University

Professor Martin Westwell was recently appointed as a strategic professor in the science of learning at Flinders University where, until this year, he was the Director of the Flinders Centre for Science Education in the 21st Century.

After completing his degree and PhD at Cambridge University, Martin moved to Oxford University as a research fellow in biological and medical sciences at Lincoln College. He left academia to pursue other interests and then returned to Oxford in 2005 as the Deputy Director of the Institute for the Future of the Mind where he ran the research program on the influence of modern lifestyles and technologies on the minds of the young and the old. Now Martin works with schools and systems across Australia with the Commonwealth Department of Education, Employment and Workplace Relations to provide some of the evidence base for the National Career Development Strategy and with UNESCO looking at the future of education in the Asia–Pacific region.

Martin and his family moved to Adelaide in September 2007. His wife, Val, is a mathematics educator and they have two boys who attend public schools.

ABSTRACT

The rhetoric of the need to move from an industrial model of education to a post-industrial model is familiar. With this in mind, the mandate to enact this transition is evident in the Australian Curriculum. The values, experience and expertise of teachers and education leaders will determine the extent to which this strategic shift is achieved and, in this context, educational neuroscience can play a key role in informing educators' decision making and practice. What are the cognitive (and so-called non-cognitive) skills that characterise effective learners and how can we incorporate the development of these skills into the strategic intent of education? As teachers innovate, how can the neuroscience research evidence give them confidence and protection, and how can it help leaders to mainstream the innovation?

THE STRATEGIC SHIFT

Education systems around the world are grappling with the changing demands of students and society, and with some fundamental shifts in the very purpose of state-funded education. In Australia, the Australian Curriculum represents one way in which these shifts are being recognised and enacted.

Industrial models of education (see for example, Van Damme, 2012) focused on linear, hierarchical models of learning in which content was king and authentic problem-solving, reasoning, inferring, judgement and creativity were the domain of so-called 'higher-order thinking'. The ways in which education was organised demanded pedagogies focused on the selection of the few, and a concept of student engagement that was more about compliance than anything else.

Post-industrial models of education were for a long time largely confined to visionary statements and inspiring presentations that, back in the classroom, seemed largely aspirational or even rhetorical. Sir Ken Robinson's TED talks and animated RSA presentation are ubiquitously known by educators (Robinson, 2006, 2010a, 2010b). They have received tens of millions of views across all platforms but it has been difficult to see how the sentiments expressed could be reflected in our classrooms. The Australian Curriculum introduces both a mandate and a mechanism to undertake a strategic shift to turn the rhetoric into action; to develop all students as effective learners with empowering transverse skills rather than 'knowers' and 'doers' (for example, European Commission, 2013; UNESCO Bangkok, 2013).

For example, based on the evidence from the National Research Council's *Adding it up* report (Kilpatrick, Swafford & Findell, 2001), the proficiencies in the Australian Curriculum: Mathematics include, but go beyond, the knowledge and know-how of the learning area. These 'industrial' skills are captured in the Fluency proficiency (see Table 1) and are considered necessary but not sufficient for anyone to be an effective learner of mathematics. If young people are to be empowered by their mathematics learning, it is necessary for them to develop the proficiencies of Understanding, Problem Solving and Reasoning in learners. Similarly, the History curriculum demands that students go beyond the knowledge and know-how of the learning area and develop ways of making judgements and interpreting historical narratives through the 'History Concepts' of evidence, continuity and change, cause and effect, perspectives, empathy, significance and contestability. Inspection of the Science and English curricula as well as the next phase of learning areas reveals the same strategic shift in which the knowledge and know-how of the learning areas are still considered as necessary components of a curriculum that serves the modern, post-industrial educational needs of Australian schoolchildren.

This educational shift brings with it new demands upon teachers and students alike. It requires much more active teaching and learning than the industrial model of instruction and training. Many of these new demands require purposeful and intentional development of students' cognition.

THE NEED TO STOP AND THINK: TAKING CONTROL OF THOUGHTS AND ACTIONS

Our earliest years are a frenzy of brain and cognitive development as we start to take control of motor function, the interpretation of sensory information, and so on (Blakemore & Frith, 2005). But it does not end there. The experiences of very young children influence the ways in which they build their cognitive skills that support their school-readiness (Bodrova & Leong, 2006). The interplay between the physical development of the brain and the development of behaviour and skills goes on throughout primary school, into secondary and through to our early twenties as various aspects of our cognition are unlocked (Best, Miller & Jones, 2009; Blakemore, 2008; Choudhury, Charman & Blakemore, 2008; Gogtay et al., 2004; Shaw et al., 2006).

In this extended period of development from early childhood to early adulthood, a shift occurs from experiencing the world in a purely sensational and emotional way to the application of increasing self-regulation and more thought-through actions. The development of this shift is strongly reflected in the Early Years Learning Framework (Department of Education, Employment and Workplace Relations – DEEWR, 2013), particularly the components of Outcome 4: Children are confident and involved learners:

- children develop dispositions for learning such as curiosity, cooperation, confidence, creativity, commitment, enthusiasm, persistence, imagination and reflexivity

- children develop a range of skills and processes such as problem solving, enquiry, experimentation, hypothesising, researching and investigating
- children transfer and adapt what they have learned from one context to another
- children resource their own learning through connecting with people, place, technologies and natural and processed materials.

The shift to more active, purposeful learning continues in the Australian Curriculum through, for example, the Mathematics Proficiencies (Table 1).

Table 1 Mathematics proficiencies from the Australian Curriculum

Fluency	Understanding	Problem solving	Reasoning
An emphasis of skills in choosing and using appropriate procedures flexibly, accurately and efficiently. It is also about recall of knowledge and concepts.	It is when students make connections between related concepts and use the familiar to develop new ideas.	There are two key elements: the solving of unfamiliar problems and solving of meaningful problems.	The capacity for logical thought and actions, such as analysing, evaluating, explaining, inferring and generalising.
Develop skills in: • *choosing* appropriate procedures • *carrying out* procedures flexibly, accurately, efficiently and appropriately • *recalling* factual knowledge and concepts	Develop the ability to: • *build a robust knowledge* of adaptable and transferable ideas • *make connections* between related ideas • *apply* the familiar to *develop* new ideas	Develop the ability to: • make choices • interpret • formulate • model • investigate • communicate solutions effectively	Develop an increasingly sophisticated capacity for logical thought and actions, such as: • analysing • proving • evaluating • explaining • inferring • justifying • generalising
So what does it look like when they demonstrate fluency? They: • *produce* answers efficiently • *recognise* robust ways of answering questions • *choose* appropriate methods • *recall definitions* • *use facts* • *manipulate* information and processes	So what does it look like when they demonstrate understanding? They: • *connect* related ideas • *represent* concepts in different ways • *identify* commonalities and differences between aspects of content • *describe* their thinking in a subject-specific way • *interpret* subject-specific information	So what does it look like when they formulate and solve problems? They: • *design* investigations • *plan* approaches • *apply* existing strategies to seek solutions • *verify* that answers are reasonable	So what does it look like when they demonstrate reasoning? They: • *explain* their thinking • *deduce* strategies • *justify* strategies and conclusions • *adapt* the known to the unknown • *transfer* learning from one context to another • *prove* (or provide evidence) that something is true or false • *compare* and contrast related ideas and explain their choices

The four proficiencies are taken from the Australian Curriculum>Mathematics>Organisation>Content Structure (Australian Curriculum, Reporting and Assessment Authority, n.d.). The text has been taken directly from the curriculum document and presented in such a way as to highlight the structure of the proficiencies. The mathematics-specific language has been slightly modified to make it more generally accessible.

The self-regulation and stop-and-think skills required to be a purposeful learner are known as 'executive functions'. They are a range of cognitive processes such as planning, prioritising, verbal-reasoning, problem solving, sustaining and switching attention, multi-tasking, initiating and monitoring actions (e.g. Diamond, 2013). As the term 'executive functions' suggests, these abilities exert some control and direction over thoughts and actions. There are three core executive functions that are interrelated and seem to underpin the other processes, such as problem solving, planning, inferring and so on, that are crucial for thinking and learning. These core executive function abilities are impulse inhibition, working memory and cognitive flexibility.

IMPULSE INHIBITION

To escape from the immediate press of the moment, whether that be not even attempting a difficult problem-solving question in the NAPLAN test, sustaining attention or choosing a familiar but inefficient approach to an investigation, it is necessary for a learner to be able to resist their habitual responses and the temptations for short-term gain while simultaneously holding at bay any distractions that will bring them back to the here and now. This ability to 'inhibit impulses' is the skill that is used to pause and filter our thoughts and actions. It makes possible the ability to purposefully focus attention, consider alternatives and weigh possibilities.

> *This capacity keeps us from acting as completely impulsive creatures who do whatever comes into our minds. It is the skill we call on to push aside daydreams about what we would rather be doing so we can focus on important tasks. It is the skill we rely on to help us 'bite our tongue' and say something nice, and to control our emotions at the same time, even when we are angry, rushed or frustrated. Children rely on this skill to … stop themselves from yelling at or hitting a child who has inadvertently bumped into them, and to ignore distractions and stay on task in school. (Centre on the Developing Child at Harvard University, 2011)*

In short, inhibitory control is the ability to resist a strong inclination to do one thing in order to do what is most appropriate or needed (Diamond, Barnett, Thomas & Munro, 2007).

> *The ability to inhibit a strong behavioral inclination helps make discipline and change possible. (To change, to get out of a behavioural rut, requires inhibition of the strong tendency to continue doing what you've been doing). Inhibition, thus, allows us a measure of control over our attention and our actions, rather than simply being controlled by external stimuli, our emotions, or habitual behavior tendencies. The concept of inhibition reminds us that it is not enough to know something or remember it. A child may know what he or she should do, and want to do that, but not be able to do it because of insufficiently developed inhibitory control. (Diamond et al., 2007)*

The industrial model of education, with its familiar routines and linear concepts of learning, promoted the development of a surface approach to learning in students, a characteristic known to drive down students' academic performance (Richardson, Abraham & Bond, 2012). Impulse inhibition is the 'stop' of 'stop and think' and is a skill if students are to be able to go beyond set routines that are limited to knowledge and know-how so that they can access the thinking required for problem solving, reasoning and understanding.

WORKING MEMORY

The ability to hold information and ideas in mind and mentally working with that information over short periods of time is known as 'working memory'. It has been described as mental workspace or jotting pad that is used to store important information that we use in the course of our everyday lives (Gathercole & Packiam-Alloway, 2008).

Many conscious mental processes rely upon working memory. For example, if you were attempting to multiply together 21 and 63 (without a calculator or pen and paper) you would store these numbers in your working memory. Regardless of the strategy you employed, you would likely break up the two-digit numbers in some way, holding the fragments in your working memory, multiply some combination of the fragments together, now holding the results of these operations in your working memory, to finally recombine them through addition. This process puts high demand upon working memory. Several number combinations have to be held in mind, as do the relationships between them if we are to be successful. Without working memory, or a surrogate such as a pen and paper, this arithmetic would be impossible.

As described by Harvard University's Centre of the Developing Child (2011):

> *Working memory … provides a mental surface on which we can place important information so that it is ready to use in the course of our everyday lives … It enables children to remember and connect information from one paragraph to the next, to perform an arithmetic problem with several steps … and to follow multiple-step instructions without reminders. It also helps children with social interactions, such as planning and acting out a skit, taking turns in group activities, or easily rejoining a game after stepping away to get a drink of water.*
>
> *Working memory is also the ability to hold information in mind despite distraction (such as holding a phone number in mind while you pause to listen to what someone has to say) and to hold information in mind while you do something else (such as holding a phone number in mind while talking about something else before dialing). The information loaded into working memory can be newly learned or retrieved from long-term storage. Working memory by its very nature is fleeting, like writing on misty glass. The ability to hold information in mind makes it possible for us to remember our plans and others' instructions, consider alternatives and make mental calculations, multi-task, and relate the present to the future or past. It is critical to our ability to see connections between seemingly unconnected items. (Diamond et al., 2007)*

Building working memory in learners allows them to bear in mind information and experiences in a way that influences their thinking and decision making. Working memory is used heavily in both the deductive reasoning that is required to apply a general idea to a specific case, and the inductive reasoning that is required to draw inferences and conclusions from reading, research or other investigations. Without this ability to bear ideas in mind, students' learning and the application of their learning is limited to the exact knowledge that educators impart or the know-how in which they have been trained.

COGNITIVE FLEXIBILITY

> *Cognitive flexibility is the capacity to nimbly switch gears and adjust to changed demands, priorities, or perspectives. It is what enables us to apply different rules in different settings. We might say one thing to a co-worker privately, but something quite different in the public context of a staff meeting … As the author of* The Executive Brain*, Goldberg (2001), notes, 'the ability to stay on track is an asset, but being "dead in the track" is not.' Stated differently, self-control and persistence are assets, rigidity is not. Cognitive flexibility enables us to catch mistakes and fix them, to revise ways of doing things in light of new information, to consider something from a fresh perspective, and to 'think outside the box.' If the 'church in two blocks' where we were told to turn right is actually a school, we adjust and turn anyway. (Centre on the Developing Child at Harvard University, 2011)*

Cognitive flexibility builds on impulse inhibition and working memory and adds an additional element

(Diamond, 2013; Diamond et al., 2007). For example, in considering alternative strategies or error corrections, the goal has to be borne in mind while the merits of different approaches are considered. Ways forward that demand least effort, or staying on the existing pathway (even if 'dead in the track') may be tempting and emotionally appealing but they must be inhibited if other options are to be thought through. The industrial model of education often reinforced the need to stay on a particular pathway with familiar processes but the post-industrial nature of the Australian Curriculum often demands the consideration and judgement required by multiple, non-linear approaches.

In effective learning processes, the ability to adjust to new information or changed demands and priorities is required (Bodrova & Leong, 2006; Luria, 1966; Shallice, 1982). In education, this flexibility allows individuals to shift priorities and explore alternative scenarios as they think through the problem or interpretation of the information at hand and the potential implications of their decisions. Cognitive flexibility can help to keep options open when appropriate, allowing for the switching between different pathways and outcomes.

The ambiguity created by weighing possibilities, considering options and making a range of links to other knowledge can create significant discomfort. Even when cognitive flexibility is being used by a learner, there is always the potential to go down the easy route and make a snap decision just to resolve this discomfort in preference for some apparent certainty.

> *People often prefer the known over the unknown, sometimes sacrificing potential rewards for the sake of surety. Overcoming impulsive preferences for certainty [is necessary] in order to exploit uncertain but potential lucrative options. (Huettel, Stowe, Gordon, Warner & Platt, 2006)*

The ability to inhibit this impulse, in combination with cognitive flexibility, is required if young people are to avoid prematurely locking in a particular way of thinking that may turn out to be sub-optimal or inappropriate. Young people without cognitive flexibility tend to adopt one of two strategies when they encounter a significant problem: they either continue along the same dead-end track, continuing to employ strategies and making choices that are demonstrably not working: or they withdraw completely (Blackwell, Trzesniewski & Dweck, 2007). Young people with higher levels of cognitive flexibility will consider whether the goal remains desirable or is achievable at all, and, if they decide that it is, they will find other ways to achieve it drawing on the experiences and expertise of their friends, parents, teachers and others who might be able to support them.

> *Flexibility of thinking is also called into play when students interpret words or language that may be ambiguous, draw inferences and conclusions, and process redundant information; actions required to process most written texts. Students need to prioritise and reprioritise information in an effort to make the text useful for their particular purpose. (Meltzer & Krishnan, 2007)*

For many young people, when they are required to make these interpretations and inferences, they will find themselves in unfamiliar territory. This puts enormous demands upon executive functions and it cannot be assumed that they will be able to effectively interpret the information they receive and the experiences they have to draw appropriate conclusions. But, this is exactly the sort of demand introduced by the Australian Curriculum. Interventions and resources to support the 'stop and think' skills that underpin thinking in interconnected ways and using judgement along the way will serve a wide range of students, especially where the context in which they are working is unfamiliar.

The extent to which young people have developed executive functions has been shown to profoundly affect their outcomes in terms of education, health, income and criminal behaviour (Margo, Dixon, Pearce & Reed, 2006; Mischel, Shoda & Rodriguez, 1989; Moffitt et al., 2011).

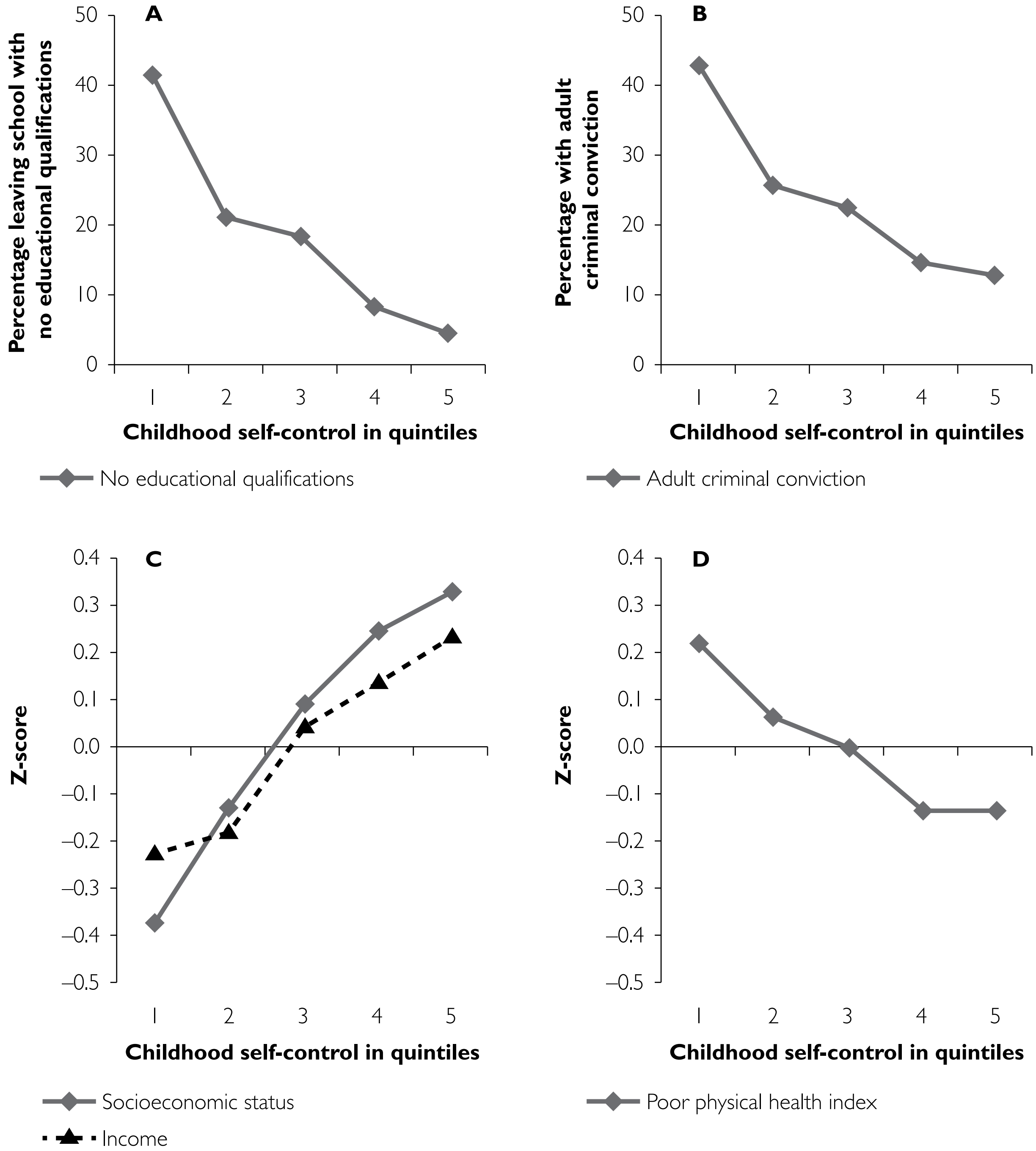


Figure 1 Impact of childhood self-control on outcomes in adulthood

For example, a study carried out in Dunedin, New Zealand, followed approximately 1000 children from birth through to adulthood and measured a range of outcomes. Individuals were assigned to a quintile depending on their childhood level of self-control. In Figure 1, Quintile 1 had the lowest levels of self-control and Quintile 5 the highest.

Children with lower levels of self-control are more likely to (A) leave school without any formal qualifications, (B) have a criminal conviction, (C) have financial difficulties, lower income and have lower socioeconomic status and (D) have poorer health outcomes by 32 years old (data from Moffitt et al., 2011). (Each quintile contains the same number of people. The Z-score is the number of standard deviations from the mean represented by each group.)

Of the group with the lowest levels of childhood self-control (Quintile 1), just over 40 per cent left school without any qualifications compared to less than 5 per cent of those in Quintile 5. The proportion of individuals without any educational qualifications decreased as the levels of childhood self-control increased across the groups (Figure 1A). This pattern was mirrored quite closely for the rate of adult criminal convictions (Figure 1B) in the population.

Given the correlation between childhood levels of self-control and school qualifications, it is unsurprising that similar correlations exist with socioeconomic status and income (Figure 1C). Typically, children from low socioeconomic status backgrounds have lower levels of self-control and executive functions. They are less likely to be able to take effective control of their thinking and learning. Due to their lower levels of executive functioning, young people from low socioeconomic status backgrounds have less cognitive capacity to support their day-to-day decision-making processes. This in turn prevents them from making the most of the educational opportunities available and traps them into low-income jobs, low socioeconomic status and poorer health outcomes (Figure 1D).

Given that poverty and low socioeconomic status do run in families, it may be tempting to think that there is an underlying genetic basis but research such as the Dunedin study shows that, while there is likely to be a genetic component that influences young people's ability to make the most of the education and employment opportunities available to them, the characteristics of their environment are crucially important. On the whole, children are not genetically predestined to be less effective learners and limited to low-income employment. Those children who are supported to develop executive functions enjoy better outcomes than those who are not.

The Dunedin study was designed as an observation-only study but some children did, for whatever reasons, improve their executive functioning and self-control.

> *[T]hose children who became more self-controlled from childhood to young adulthood had better outcomes by the age of 32 y[ears], even after controlling for their initial levels of childhood self-control. (Moffitt et al., 2011)*

This finding suggests that levels of executive functions can be improved and, for those individuals who are supported in doing so, these enhanced skills lead to enhanced outcomes including educational attainment, income and socioeconomic status.

The industrial model of education, with its focus on compliance and the development of routine skills, served a funnel-and-filter structure that drove pedagogies for the selection of the few. This model no longer serves the needs of any of our young people to be effective children and adolescents in the modern era and neither does it prepare them for their uncertain future. This need for a strategic shift has been recognised by education systems around the world and enacted here by the Australian Curriculum. The curriculum's Mathematics Proficiencies, the Science as a Human Endeavour strand, the History Concepts and the focus on depth and the receptive and productive aspects of English are all potential game-changers. From compliance, routine and selection of the few, the Australian Curriculum creates a mandate for empowerment, judgement and successful development of all.

The implementation of the Australian Curriculum has the potential to position Australia as a world leader in education. To realise this promise, research evidence from educational neuroscience and elsewhere can be used to inform the decision making and practice of educators and learners. Looking at the Australian Curriculum through the lens of the research findings highlights some of the cognitive abilities that will be needed by educators and as part of the strategic shift to a truly post-industrial education system. Together, impulse inhibition, working memory and cognitive flexibility allow an individual to escape from industrial, surface approaches to teaching and learning such that they are able to take control of their thoughts and actions, essentially allowing them to capitalise on these new opportunities by stopping and thinking (Best et al., 2009; Grosbras et al., 2007; Andrews-Hanna, Mackiewicz Seghete, Claus, Burgess, Ruzic & Banich, 2011).

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MEASURING LEARNING IN COMPLEX LEARNING ENVIRONMENTS

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ABSTRACT

Technology offers the opportunity to enhance the learning experience through providing students with learning environments that bring to them other worlds outside the classroom. For example, the use of animations, simulations and augmented reality can help to show dynamic processes such as geological events over time, virtual chemistry laboratories or events from history in deeper and richer ways than are possible in textbooks. These technological tools also offer the chance to allow students to explore and manipulate the virtual environments that are created, bringing opportunities for learners to engage in the construction of knowledge rather than just receiving facts. But, as the learning environments become more complex and the number of paths that students can take through them increases, how can teachers be assured that their students are learning what was intended? How can we measure learning in such a way that ensures students get feedback at the right time and teachers remain in touch with how their students are progressing? This session explores how learning can be traced in complex learning environments that use technology and illustrates the techniques from several projects that have been developed to do that.

HOW INTERACTIVE LEARNING ENVIRONMENTS CAN ASSIST STUDENT LEARNING

Interactive learning environments hold a lot of promise for assisting learners in ways that are tailored to the needs of each learner. Well-designed interactive learning environments combine pedagogical approaches that are based on cognitive theory of learning in interactive ways in electronic environments with methods of measuring the progress of learners and techniques for providing assistance at key moments.

This paper focuses on how interactive learning environments can support student learning in science, a curriculum area in which there is an increasing emphasis on understanding scientific concepts and on developing skills in applying science inquiry practices. In science, students often have difficulty connecting concepts to real world phenomena and in understanding how to use scientific practices in investigating those phenomena (TIMSS, 2008). Studies in the USA point to the lack of ‘rigorous and excellent’ instruction in US schools on science inquiry skills – those that build students’ ability to form ideas or hypotheses about phenomena and to design experiments to test those ideas (Weiss & Pasley, 2004).

This paper demonstrates how three interactive learning environments, which were designed for instructing students in developing their understanding and science inquiry practices across several areas of science, dealt with the challenges of supporting learning of complex concepts in interactive ways using technology. These are the three interactive learning environments:

- ChemVlab+ (http://www.chemvlab.org) – an interactive learning environment in which secondary students work with a virtual chemistry laboratory to undertake tasks in a series of embedded assessment modules that provide them with opportunities to apply chemistry knowledge in meaningful contexts and to receive immediate, individualised tutoring. The four modules cover concentration, unit conversion, molar mass, balancing reactions and using stoichiometry.
- SimScientists (http://www.simscientists.org) – a suite of modules that use simulations to enrich science learning and assessment for students in middle school and secondary school. Science simulations can be used in curriculum activities as embedded, formative assessments and as summative assessments. The SimScientists modules cover topics in life science (ecosystems and cells; human body systems), physical science (forces and motion; atoms and molecules) and Earth science (climate; plate tectonics).
- Voyage to Galapagos – The Voyage to Galapagos provides middle school students with an interactive learning environment in which they can follow in the footsteps of Charles Darwin by doing simulated exploration of a selection of the Galapagos Islands. Students collect and then analyse data on iguanas to arrive at specific connections among the key concepts of variation, function and natural selection.

THE CHALLENGE OF PROVIDING ASSISTANCE IN INQUIRY SCIENCE INSTRUCTION

The goal of inquiry learning is to allow students to induce the characteristics of a domain through their own experiments and exploration (de Jong, 2006). But, even in curricula with hands-on laboratories and the opportunity to engage in inquiry learning, students are typically asked to replicate standard experiments rather than perform their own inquiries. Critics of such approaches say they are limited to ‘transmitting’ science rather than teaching its practices (Duschl, Schweingruber & Shouse, 2007). This pedagogical approach is likely to contribute to the reported difficulties students have in designing and conducting scientific experiments; for instance, by varying more than one variable at a time (Keselman, 2003), by incorrectly interpreting data (Lewis, Stern & Linn, 1993) and by sticking with preconceived ideas in the face of contradictory data (Chinn & Brewer, 1993, 2001).

On the other hand, a variety of research has suggested that, *with appropriate guidance*, students can learn about science and successfully engage in scientific inquiry, including taking the well-established steps followed by professional scientists, such as making hypotheses, gathering evidence, designing experiments and evaluating hypotheses in light of evidence (Chen & Klahr, 1999; de Jong & van Joolingen, 1998; Klahr & Dunbar, 1988; Lehrer & Schauble, 2002; Njoo & de Jong, 1993). Theory about how best to scaffold inquiry learning has also emerged (Edelson, 2001; Quintana et al., 2004). Building on these fundamental findings and theory, a variety of researchers have developed simulations, cognitive tools and scaffolding to support the kind of reasoning that underlies inquiry learning in science. Research on scaffolded inquiry learning suggests that teaching the critically important skills associated with scientific inquiry can be greatly improved if supported by the right kind of guidance (Linn & Hsi, 2000; Sandoval & Reiser, 2004; Slotta, 2004; van Joolingen, de Jong, Lazonder, Savelsbergh & Manlove, 2005; White & Frederiksen, 1998).

But what exactly is the right amount and type of guidance? While past work with inquiry learning environments makes clear that *some* guidance is necessary, it doesn't fully answer this question, which in the learning sciences more generally has been variously investigated under the guise of 'desirable difficulty' (Schmidt & Bjork, 1992), the 'assistance dilemma' (Koedinger & Aleven, 2007) and 'productive failure' (Kapur, 2009). Essentially the issue is to find the right balance between, on the one hand, full support and, on the other hand, allowing students to make their own decisions and, at times, mistakes. There are cost benefits associated with each end of this spectrum. *Assistance giving* allows students to move forwards when they are struggling and to experience success, yet can lead to shallow learning, non-activation of long-term memory and the lack of motivation to learn on their own. On the other hand, *assistance withholding* encourages students to think and learn for themselves, yet can lead to floundering, frustration and wasted time when students are unsure of what to do. Advocates of direct instruction point to the many studies that show the advantages of giving assistance (Kirschner, Sweller & Clark, 2006; Mayer, 2004), but this still does not acknowledge the subtlety of exactly how and when instruction should be made available, particularly in light of the differences in domains and learners (Klahr, 2009).

Grappling with the assistance dilemma requires, at least in part, an understanding of the human cognitive architecture. It is well established in cognitive science that humans have both a working memory, where conscious processing occurs, and a long-term memory, where our extensive experience and knowledge resides (Atkinson & Shiffrin, 1968). Long-term memory is critical to what we 'know' – unless an educational activity changes long-term memory, we have not learned anything. Further, learning is subject to the severe limitations of working memory (Sweller 2003, 2004), both in capacity (estimated to be a very small number of elements: three to seven) and duration (unrehearsed information disappears within 30 seconds). When students are confronted with new content in an unfamiliar environment, such as an inquiry-learning tool, their working memory is easily and quickly overloaded unless strong guidance is provided to focus them on relevant information and tasks. As students become more familiar with the material and environment, through transfer of information to long-term memory, they are typically able to focus on the right content and choose the correct steps to take without as much guidance and without experiencing cognitive overload.

Not surprisingly, in light of this theory, studies of how human tutors deploy both the frequency and the nature of assistance have shown that effective tutors adapt their support based on the ability level of the student. Katz, Allbritton and Connelly (2003) found differences in the feedback tutors gave to students who had (unknown to the tutors) scored low on a pretest versus those who scored well. The differences in the frequency and nature of the assistance provided was based on the tutor's perception of the relative abilities – and therefore needs – of each student.

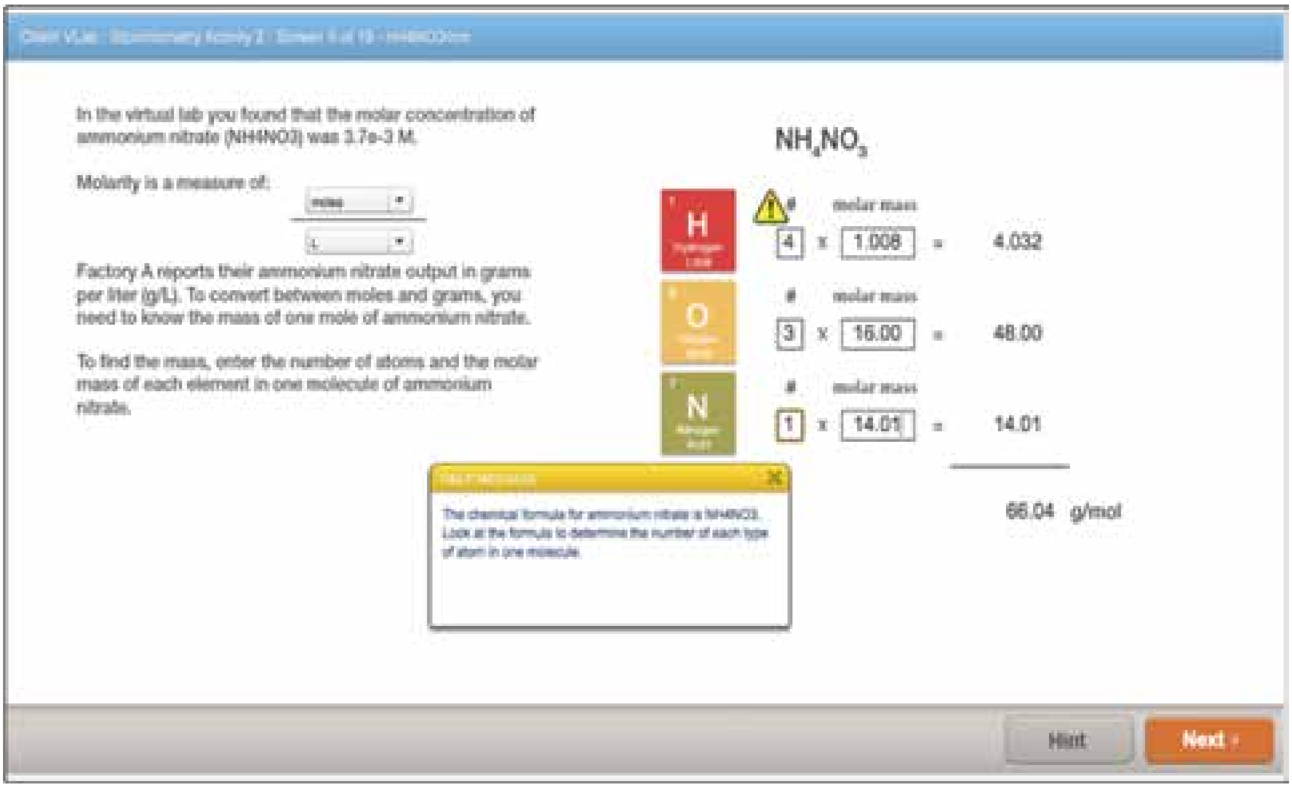

Figure 1 Screenshot that shows how ChemVlab+ provides feedback and coaching to students

EXAMPLES OF INTERACTIVE LEARNING ENVIRONMENTS

The three interactive learning environments employ two different techniques to detect students' need for help and to deliver assistance as they complete the tasks they are set. The ChemVlab+ and SimScientists projects use contingent-based modelling in which the systems are designed to detect when students are making errors or behaving in ways that are known to be unproductive. When these contingent behaviours are detected, the system is designed to flag the error and offer a sequence of hints that lead the student to a productive solution. An example from the ChemVlab+ is shown in Figure 1.

The feedback that student receive is differentiated based on their needs. When a student makes a response and clicks on the 'Next' button in the bottom right of the screen, the system evaluates the student's work on that screen through applying a logic structure that determines the correctness and, if incorrect, the nature of the misconception that the student has. Figure 1 shows how the system provides a symbol (! in a triangle) where a hint is available, and the hint text that the student has been given. A student may also call for a hint by pressing the 'Hint' button, but only receives it when the system judges that a hint is needed.

The Voyage to Galapagos is a more open-ended learning environment and employs a more complex system to detect a students' need for help. It uses a Bayesian network to represent the contingent-based model, which is a way of keeping tally of actions that the student takes which suggest that he or she is not on a productive learning path. For example, in Figure 2 the student is part-way through a task in which he or she has to photograph a sample of iguanas that show variation in their physical traits. The panel on the lower right shows a map view of the path the student is taking around the island and the main panel on the left shows the view as the student follows that path. An iguana is in the bottom of the view. If the student needs more iguanas in the sample, but moves on without taking a photo, the system detects this and passes that data to the Bayes Net. Each such incident increases the probability that the student needs help with data collection and, if the student continues to pass by iguanas, the system eventually will prompt the student by flagging the missed iguana and indicating that it needs to be added to the sample. Our research study in Voyage to Galapagos is looking at what mixture of assistance is best for which kind of learner and the Bayes Net system can be used to trigger a range of levels of help.

Figure 2 Screenshot that shows how a student task in Voyage to Galapagos can provide data on when a student needs help.

Table 1 Gaps in total performance between English learners or students with disabilities and the general population

Group	Ecosystems post-test (%)	Force and motion post-test (%)	Ecosystems benchmark (%)	Force and motion benchmark (%)
English learners	24.0 (n = 123)	27.4 (n = 50)	10.6 (n = 126)	13.6 (n = 50)
Students with disabilities	20.2 (n = 183)	15.7 (n = 153)	8.4 (n = 189)	7.0 (n = 153)

IMPACT

Results from trials of the SimScientists and ChemVlab+ modules indicate that the kinds of feedback built into the systems are producing learning gains and, more interestingly, that they might benefit particular students.

In a study of two of the SimScientists modules, the use of interactive assessments produced higher outcomes compared to performance on traditional multiple-choice assessment items (Quellmalz, Timms, Silberglitt & Buckley, 2012). Overall, students performed better on the interactive assessments than on the multiple-choice post-test, and performance gaps between both English-language learners and students with disabilities compared to other students were reduced on the interactive assessment. Table 1 compares performance gaps of both these student groups to a reference group of all other students.

The gaps between the focal groups and the reference group are comparatively smaller than for the post-test. This indicates that the multiple representations in the simulations and active manipulations may help English-language learners and students with disabilities to understand the assessment tasks and questions and to respond.

In a study of the ChemVlab+ modules, we were interested in whether the activities produced learning overall, as well as whether the schools with differing student demographics benefited similarly from the instructional activities. School A was in a low-income area in which almost half the students qualified for free or reduced-price lunches and only 26 per cent of students had scored at proficient level on the state science test. School B had 20 per cent of students eligible for free or reduced-price lunches and 40 per cent of students were proficient on the science test. School C was in a wealthier area in which only 8 per cent of the students qualified for free or reduced-price lunches and 70 per cent were proficient in science. Students took a pre- or post-test that comprised 15 multiple-choice and open-ended items with a maximum score of 30 points.

Figure 3 shows that for schools A and B, post-test scores were significantly higher than pre-test scores. At School A, where a higher proportion of students were disadvantaged, overall scores were lower, but the change from pre- to post-test was higher. The average of the post-tests was 13.4 while the pre-test average was 9.4 ($p < 0.001$, $t = 9.86$, $n = 102$ students), which represents an effect size of 0.68 (Cohen's d). The second-highest gains were at School B, which had a moderate proportion of disadvantaged students. At School B, the average of the post-tests was 15.6 while the pre-test average was 13.0 ($p < 0.001$, $t = 6.75$, $n = 147$ students), an effect size of 0.48. For School C, where there were hardly any disadvantaged students, there was a gain from 15.84 at pre-test to 16.4 at post-test ($p < 0.2$, $t = 1.1$, $n = 81$), but the difference was not significantly different. This indicates that the interactive learning materials seemed to have an increased effect for disadvantaged students.

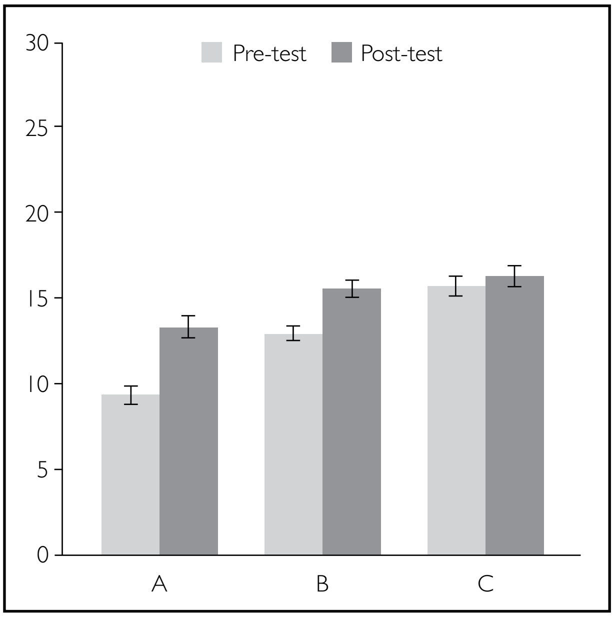

Figure 3 Comparison of the pre- to post-test learning outcomes for three schools in the ChemVlab+ pilot study (error bars indicate one standard error) (Davenport, Rafferty & Timms, 2013)

At the time of writing this paper, we have not yet pilot tested the Voyage to Galapagos learning environment.

Overall, the use of interactive learning environments appears to have differential effects that enable students who are disadvantaged, are not native English speakers or have disabilities that affect their learning to improve their performance relative to their peers.

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THE BRAIN, EARLY DEVELOPMENT AND LEARNING

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Associate Professor Michael Nagel has more than 25 years experience in various forms of education on three continents. Dr Nagel's research and teaching interests extend across a number of areas but he is most interested in human development and the psychology of learning. His PhD research encompassed an international project that looked at the learning experiences of Australian and Canadian teenagers. Before his arrival at USC, Dr Nagel spent time in the USA, researching neurological development in children, with a particular interest in early and adolescent development and areas related to a sexually dimorphic brain. In 2006 his book *Boys-stir-us: Working WITH the hidden nature of boys* was released in Australia, followed in 2008 by *It's a girl thing: Schooling and the developing female brain*.

In 2012 his two newest books were released. *In the beginning: The brain, early development and learning* and *Nurturing a healthy mind: Doing what matters most for your child's developing brain* complement his previous volumes of work but focus on neurological development in children from birth to the age of eight years. They have been written for any person whose professional interests encompass child development, learning and parenting respectively. He is currently working on his next volume of work entitled *In the middle: The adolescent brain, behaviour and learning*, which is to be published by ACER and released in early 2014.

Aside from his teaching and research activity at the university, Dr Nagel has also conducted workshops and seminars for teachers and parents at more than 200 schools in Australia and abroad.

Twice nominated as Australian Lecturer of the Year, Dr Nagel has also won a number of awards for linking theory with the everyday realities of raising and working with children, and he is a feature writer for the *Child* series of magazines, which offer parenting advice to more than 1 million Australian readers.

Dr Nagel is keenly interested in all facets of education and child development but his primary motivation is helping to ensure that schools and 'schooling' are positive and enriching experiences for 21st-century students and teachers alike.

ABSTRACT

Since the 1990s, advances in technology and scientific research have provided new insights into the neurological development of children. As a result of this work, all aspects of education and child care have been reinvigorated with new understandings of how the brain grows and develops, how this might affect behaviour and learning and ultimately how early experiences may shape who we become as we grow into adulthood. Worryingly, neuroscientific research has also been used to perpetuate a number of neuro-myths focusing on enrichment and building 'better brains'. This presentation focuses on debunking a number of those myths by looking at contemporary research into how the brain matures and develops, how nurture affects nature and the implications of this as we engage with children in various educational contexts.

> *[I]n order to develop normally, a child needs the enduring irrational involvement of one or more adults in care of and in joint activity with that child. In short,* somebody has got to be crazy about that kid. *(Bronfenbrenner 2005, p. 262)*

While it is widely recognised that the path to a nation's future prosperity and security begins with the wellbeing of all children, only recently have we been able to identify the important links between this sense of prosperity in conjunction with experience, environment and brain development. Science tells us that early experiences determine whether a child's developing brain architecture provides a strong or weak foundation for the future of all aspects of learning, behaviour and health and, by association, the foundation for contributions to society in general (Center on the Developing Child, 2007). For decades a range of academic and research disciplines have been aware of the extraordinary development of a child's brain during the first few years of life. Recent advances in neuroscience have helped crystallise earlier findings, bringing new clarity and understanding to parents, educators, policy makers and all those concerned with early childhood brain development. This discussion focuses on unpacking some of the most recent findings regarding the developing brain and the implications of this on raising and educating young minds.

NEUROSCIENCE AND BRAIN DEVELOPMENT: A CAUTIONARY TALE

The human brain has been a topic of interest and curiosity for countless generations. Some of the earliest known writings about the brain date back to 4000 BC and it is safe to say that interest in the gelatinous mass between our ears has never waned. In the early 1990s, advances in technology made it possible for researchers to literally look at the brain in action and today newer technology is allowing scientists to watch the brain at a cellular level. But, whether it be by accident or through artistic licence, advances in technology and brain science have also seen the rise of a number of 'neuro-myths' related to the brain and early development and, as such, it is important to debunk such myths at the outset of this work.

Perhaps the most prominent myth surrounding early development focuses on the whimsical notion that parents or teachers or both can actively enhance a child's academic prowess through various enrichment activities. This myth was born out of the science that tells us that early experiences help to shape the brain and mind of a child. We now know that the way a brain develops hinges on the complex interplay between the genes a person is born with and the experiences a person has from birth onwards; while it is indeed true that experiences are important, the notion of somehow providing 'enriched' activities to accelerate cognitive capacities is, to date, beyond our nurturing capabilities for a number of reasons (Aamodt & Wang, 2011; Berk, 2006; Diamond & Hopson, 1999; Fox, Levitt & Nelson, 2010; Nagel, 2012).

First, and with regards to experience, the brain actually *expects* some types of experiences to occur and *depends on* others on the road to normal development (Nagel, 2012). For example, in order for a child's visual system to develop properly, the brain expects to have opportunities to see things and this obviously becomes much more readily available when a child leaves the womb. Every time an infant sees something, hears something, smells something, tastes something or feels something, its brain is rapidly building a network of neural complexity that will become a superhighway for learning. The type of stimulation expected by the brain is usually readily available in 'normal' healthy, safe, supportive and loving environments.

Second, and in contrast to the experiences a child's brain expects to have happen, the experiences it depends on are adaptive processes that arise from specific contexts and the unique features of a child's individual environment. In other words, the brain depends on particular experiences to learn how to do things such as reading a book or riding a bicycle and this is where the science of brain development is often misinterpreted or misused under the guise of enrichment. The last couple of decades have seen an expansive market of brain 'enriching' toys and tuition programs purporting to do everything from teaching two-year-olds to read to enhancing one hemisphere over the other to making bilingual babies via language DVDs. It is misleading to think that a child's brain can be systematically improved or that learning can be accelerated by providing excessive levels of stimulation. Indeed, it appears that the brain actually has a neurological timetable that extends from birth through childhood and into adulthood and it is mediated by various structures and processes. In order to understand this some insights into brain development and brain structures are warranted.

BRAIN DEVELOPMENT: MORE MARATHON THAN SPRINT

The formation of the brain and its architecture is a journey encompassing the first three decades of life. Indeed, even into a person's twenties, the brain is changing and maturing and, while adolescence sees a significant restructuring of the brain, it is in the earliest stages of life that our neural foundations are created. Early brain formation occurs not long after conception when the neural tube closes, neurons generate and the brain begins to take shape (Nagel, 2012; Nelson, de Haan & Thomas, 2006). During this early period of brain development, we have our first glimpse of how 'learning' takes place when neurons speak to each other and form connections through electrochemical impulses called synapses. These connections are influenced by both genetics and the environment and, the more repetitive an experience, the greater the opportunity to permanently hardwire these connections or, simply stated, the more the brain learns (Chugani, 1997, 2004). But it is important to remember that, although synaptic connections are formed in the womb, much of the brain's neural architecture is formed when a child enters the world.

At birth, the hundreds of billions of neurons that humans are born with continue to make synaptic connections via sensory stimulation from the environment ultimately 'wiring' the brain for action. It is significant to emphasise that the experiences an individual has affect the types and amount of synaptic connections that are made. Synaptic connections are created at a rapid rate to the age of three years and the brain actually operates on a 'use it or lose it' principle (Diamond & Hopson, 1999; Healy, 2004; Herschkowitz & Herschkowitz, 2004; Shonkoff & Phillips, 2000). In other words, only those connections and pathways that are activated frequently are retained. Other connections that are not consistently used will be pruned or discarded, most notably through the teenage years, so that the active connections can become stronger and more efficient. This process, in turn, maintains some important considerations in terms of early development and learning.

First, it is important to remember that for children's brains to become highly developed for learning, repeated experiences are essential (Aamodt & Wang, 2011; Howard, 2006). Connections become stronger and more efficient through repeated use. Reading to children every day, for example, helps strengthen essential connections. Connections are also made stronger when children have daily opportunities to develop both large- and small-muscle skills, have the chance to practise developing social skills and interact directly with their environment. This is one of the reasons that 'play' is such an important component across all aspects of early development. It is also vital to incorporate rich language into all of these activities, since exposure to rich language creates the foundation for a child's use and understanding of words, and increases the likelihood of reading success at a later age. Research shows that the richness of a young child's verbal interactions has a dramatic effect on vocabulary and school readiness, with differences correlated to socioeconomic status. A watershed study on the topic found that by the age of three, the observed cumulative vocabulary for children in professional families was 1116 words; for working-class families it was about 740, and for welfare families 525 (Hart & Risley, 1995). Studies such as this remind us that nature and nurture are intimately connected (Fox, Levitt & Nelson, 2010).

Second, and as noted above, while stimulation from the environment is important, other factors play an equally important role. Through early childhood and into adolescence, the development of the brain and mind is significantly influenced by myelin, a fatty material that insulates an important part of the neuron known as the axon (Howard, 2006). Current research identifies that the escalation of myelin occurs in various stages with a substantive increase in this important white substance during adolescence (Giedd et al., 1999; Paus et al., 1999, 2001; Durston et al., 2001; Sowell et al., 2003). Myelin is important because it aids in the transmission of information from one neuron to another and the more 'myelinated' axons in the brain, the greater opportunity for neural information to be passed quickly. The end result of all of this is that certain activities may be easier to learn when regions of the brain are sufficiently myelinated or when or brains become 'fatter' (Berninger & Richards, 2002; Eliot, 2000; Shonkoff & Phillips, 2000). At birth we have few myelinated axons. This is one reason visual acuity and motor coordination are so limited during the first days of life: the neural networks responsible for facilitating vision and movement aren't working fast enough and will become much more efficient when myelin increases. Furthermore, as we grow older, different regions of the brain myelinate at different ages. For example, when Broca's area, the region of the brain responsible for language production, myelinates, children are then able to develop speech and grammar. To that end it is important to remember that a healthy brain knows which areas need to be myelinated first, that myelination cannot happen all at once and that it cannot be accelerated via flashcards, extra tuition or the latest 'learning' toy (Diamond & Hopson, 1999; Herschkowitz & Herschkowitz, 2004; Kotulak, 1996; Nagel, 2012). This is also why any enrichment agenda postulated to enhance learning must be scrutinised carefully.

The road to brain maturation takes time and, by association, so too do a range of developmental and learning capacities. Worryingly, there are those who might suggest, or advocate, that if experience and activity are indeed significant factors in neural development then surely the earlier the stimulation (read 'enrichment') the greater the propensity for learning and early success. But, while we know that input from the environment helps to shape the brain and that experience is important, equally important is the fact that each child is an individual with similar but not identical developmental timelines (Healy, 2004; Hirsch-Pasek & Golinkoff, 2004; Nagel, 2012). Moreover, it is also not possible to accelerate emotional maturation since the emotional region of the brain (limbic system) has its own developmental clock and as such how do we ensure that trying to push children to do things too soon does not ultimately result in engulfing children in undue stress beyond their emotional coping abilities? For some children, trying to do too much too soon can lead to stress-related anxieties that actually turn off thinking processes. It is these types of considerations that should inform any foundation related to how we nurture a child's developing mind. Indeed, for all children, the road to nurturing healthy brain development is not too difficult for parents, teachers and other caregivers to follow. Children do not have to be hyper-stimulated or prepped for university by the time they are five years old. There isn't a magic formula for improving one hemisphere over another and while Mozart is a joy to listen to it will not help children become more mathematically inclined or smarter. What will help healthy brain development in children are regular routines and consistency, opportunities to consolidate learning through repetition, hands-on interactions and activities, novel ways to learn through exploration and experimentation, exposure to rich, interactive language and, most importantly, positive, reliable and supportive relationships or, as noted earlier, adults who are crazy about kids (Bronfenbrenner, 2005; Eliot, 2000; Hirsch-Pasek & Golinkoff, 2004; Nagel, 2012).

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A PEDAGOGICAL DECALOGUE:
DISCERNING THE PRACTICAL IMPLICATIONS OF BRAIN-BASED LEARNING RESEARCH ON PEDAGOGICAL PRACTICE IN CATHOLIC SCHOOLS

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ABSTRACT

In an era where professional standards and the quality of the teaching profession are increasingly being brought into the public spotlight, it behoves educational leaders and policy makers to carefully analyse research from a number of interrelated disciplines to discern more precisely what 'effective teaching' actually looks like within a classroom setting.

Many teachers have a very eclectic approach to pedagogy and, by and large, their pedagogical processes are based on intuitive judgements and the wisdom of experience. While in no way devaluing the experience of teachers, research indicates that teachers have a tendency to emphasise the overt and pragmatic aspects of the pedagogical process – such as capturing the attention of students – over other more subtle, but equally important, dimensions of learning that include personalising learning and having students construct their own insights and meaning.

The purpose of this paper is to explore a 'decalogue' of insights generated by research into brain-based learning theory, and discern their practical implications for pedagogical practice in the classroom. In particular, the paper will highlight how brain-based research has helped to inform and shape the development of the 'DEEP' pedagogical framework that has positively influenced classroom practice in Catholic schools in Tasmania and Sydney.

INTRODUCTION

Over recent decades, advances in neurological science have intrigued and inspired educators in their perpetual quest to enhance the learning outcomes of their students. Brain-based learning involves drawing insights and connections from the field of neurological research and applying them to an educational context. The emerging learning theory attempts to conceptualise and integrate 'traditional' understandings of learning, arising from psychology and sociology, with 'new' insights emerging from neurological research (Jensen, 2005; Sousa, 2006; Wolfe, 2010). In essence, brain-based education involves 'designing and orchestrating lifelike, enriching and appropriate experiences for learners' and ensuring that 'students process experience in such a way as to increase the extraction of meaning' (Caine & Caine, 1994, p. 8).

The focus on neurological research was brought to prominence most recently by President Barack Obama's announcement of an initiative to unlock the mysteries of the brain:

> *Now, as humans, we can identify galaxies light years away. We can study particles smaller than an atom, but we still haven't unlocked the mystery of the three pounds of matter that sits between our ears. (Obama, 2013)*

By pledging to devote over $100 million to a range of research projects, the President challenged neuroscientists to more comprehensively map the human brain so as to create pathways that may lead to 'the cure of diseases like Alzheimer's or autism'. While initially having a public health focus, the potential implication of this initiative for education is readily apparent.

In the past decade in Australia there has been a renewed community focus on the quality of educational outcomes. The performance of Australian students as gauged by international testing regimens suggests that, in relative terms, the Australian cohort has declined in performance levels relative to comparable OECD countries (Masters, 2012). Political leaders from both sides of the spectrum have emphasised the importance of strengthening curriculum expectations via the Australian Curriculum, and of enhancing teacher quality with special reference to Australian Institute for Teaching and School Leadership (AITSL) teaching standards as key components of a sustained school improvement process linked to the proposed Gonski (Commonwealth government) funding reforms. In essence, educational leaders are being challenged to carefully examine the pedagogical practice of classroom teachers with a view to delivering quantifiable and qualitative improvements to student learning outcomes.

The purpose of this paper is to explore and critically reflect upon a 'decalogue' of pedagogical insights gleaned from brain-based research by the author both as a researcher and teacher educator in Catholic schools in Australia over the past decade. The paper draws upon an iterative series of action research projects conducted in Tasmanian Catholic primary schools (White, 2005) and extensive dialogue and feedback from educators in association with presentation of workshops on the pedagogical resource books *Deep thinking* (White, White & O'Brien, 2006) and *Desert wisdom* (O'Brien & White, 2010).

LESSON ONE – 'THINK TIME': SO SIMPLE AND SO EFFECTIVE!

Tracking the evaluations of teachers from more than 100 professional learning workshops linking pedagogy and brain-based learning theory revealed an interesting recurring theme. While participants valued the scientific insights into the neurological functioning of the brain, the simple concept of 'think time' was one of their 'top three' pedagogical 'learnings' from the day. First introduced as 'wait time' by Rowe (1987) and further refined as 'think time' by Stahl (1994) the concept of think time resonated with the instinctive awareness of teachers who freely admitted they often overlooked the practice within the complexity of a teaching day.

From the perspective of brain-based learning principles, placing an emphasis on think time is compelling. Given (2000) noted that the main difficulty the brain experiences when thinking is confusion. In order to undertake neural encoding processes, people need opportunities for reflection in order for the brain to transfer learning and construct meaning. By slowing down and focusing the thought process, more effective learning takes place. Caine and Caine (1995) observed such learning does not just occur in fixed, structured time periods: rather, the brain needs 'actual' time to explore a point of view or master a specific skill. Reflective practice is crucial to the learning process: it allows the brain to make learning personal, purposeful, meaningful and relevant (Fogarty, 1998).

Hence the brain needs 'wait time' to think and make connections. Pattern-seeking processes strive to make sense out of chaos. Pedagogically it is important to give the brain some down-time in order to play around with the information, which is essential to detect patterns. Ben-Hur (1998) asserted that the average teacher only pauses for two to three seconds after asking a question before seeking a response. If no answer is forthcoming, teachers reframe the question at a lower level of intellectual functioning. Recent research by Holt (2012) demonstrated that explicitly providing think time improved the reading comprehension levels of primary school students. Teachers need to be patient and allow wait time for answers, while students need to be encouraged to 'think aloud' without necessarily having the complete answer.

LESSON TWO – ENGAGEMENT: THE BRAIN DOESN'T ENGAGE WITHOUT A PROBLEM TO SOLVE!

A major, though unsurprising, research finding from an investigation into the pedagogical practice of primary school teachers in Tasmania (White, 2005) was the overwhelming desire of teachers to use strategies that would maximise the engagement of their students. In identifying the criteria that would underpin a high-quality 'thinking strategy', teachers were twice as likely to nominate items specifically designed to foster student engagement (for example, problem based, relevance, non-threatening) in contrast to meaning making, differentiation or collaborative learning.

In essence, this simply validates the fundamental premise of a brain-based approach: the brain won't engage without have a real problem to solve. Jensen (1998) claimed the acquisition of knowledge is directly related to the formation of new synaptic connections. These connections are formed when the experiences are novel, challenging and coherent. Alternatively, he suggested, if the experiences are incoherent, it is possible that no learning will result.

The brain hasn't evolved by simply absorbing a whole array of disjointed data: it needs to process and make sense of the experiences it is encountering. As Walsh (2000) suggested, the brain requires the challenge of figuring out patterns and discerning meaning if real learning is to occur. Hence it is no surprise that inquiry-based pedagogies, supported by brain research, feature prominently in any contemporary approach to student learning.

LESSON THREE: THE LIMBIC SYSTEM: THE BRAIN'S CENTRE FOR 'SNAKES AND LADDERS'

An area of particular interest to many teachers in the workshop sessions was the role the limbic system performs in the learning process. From a pedagogical perspective, the articulation of simplified physiological models of the brain in a professional learning context helped educators to develop a rudimentary understanding of the role of emotion in brain functioning. The presentation of basic physiological models, such as MacLean's (1978) Triune Brain, that illustrate the three main evolutionary levels of the brain ('reptilian' brain stem, limbic, neocortex) was helpful in assisting teachers to appreciate that the initial reception point for most sensory data was the limbic system of the brain. Focus group discussions revealed teachers generally believed that effective learning (for example, data sifting, critical and lateral thinking, meaning making) occurred primarily within the cerebral cortex, without appreciating the crucial filtering role played by the initial receptor, the limbic system, which deals with emotion, form and sequence. As Goleman (1996) noted, the limbic area is the major 'gating' system that allows the brain to discern any perceived emotional threats before upshifting (the 'ladders') to any form of high-level thinking activity or downshifting (the 'snakes') to a 'fight or flight' survival response.

It was illustrated in the 2005 research project that most experienced teachers are aware of the positive impact emotional stimuli could have on learning, as well as how the personal emotional state of the learner could inhibit the learning experience. Brain-based learning theory both validates and explains this intuitive insight. For example, Given (2000) emphasised the capacity of the limbic system to produce serotonin and opioids: 'feel good' chemical and neurotransmitters. When the brain is in a state of relaxed alertness, these chemicals generate positive energy and orient the learner to constructive engagement. Alternatively, when confronted with emotional trauma, learning experiences beyond the proximal zone and negative feelings of self-worth, the chemical balance of the limbic system is altered and learning is inhibited.

Similarly Tomlinson and Kalbfleisch (1998) reported that emotional stress results in an overproduction of noradrenaline that leads the brain to focus attention on self-protection in preference to learning. Learners develop either a 'fight or flight' response resulting in misbehaviour or withdrawal from the learning context. Hence, a pedagogical response should acknowledge that tasks need to be structured in a manner that allows the more emotionally vulnerable students to be able to make a start, while allowing the more secure and capable learners the flexibility and freedom to pursue the upper limits of learning.

LESSON FOUR – DIFFERENTIATION: THE 'HOLY GRAIL' OF BRAIN-BASED LEARNING THEORY?

Since the original concept of a model of the bicameral brain (Sperry, 1968), a diverse range of progressively more sophisticated brain-based learning frameworks has emerged: for example, whole brain thinking (Herrmann, 1988); the visual, auditory, kinaesthetic (VAK) model (Ward & Daley, 1993); multiple intelligences (Gardner, 1999); integral learning (Atkin, 2000). Each model has endeavoured to incorporate insights from brain-based learning research and use it to assist educators to find the holy grail of education: the capacity to cater for the unique learning needs of every student in a complex and diverse classroom environment.

While various brain-based learning style theories have the potential to support differentiation, simplistic allegiance and an over-reliance on any one paradigm has exposed the inherent limitations of any theory that seeks to simplify the enormous complexity of the human brain. From the iterative dialogue across a range of professional workshops, it is apparent that a significant limitation of educational interventions based on learning or cognitive styles has been the inability of practitioners to accurately identify the individual learning preferences of students and precisely match instructional regimens to their learning needs. Similarly, the notion that focusing on individual students' preferred learning modality (for example, spatial intelligence, musical intelligence) is innately advantageous to learning, is at best questionable and at worst significantly curtails the learner's capacity to adapt to the learning demands that will confront them beyond the security of the classroom. A more holistic notion that learning is best accessed via one's cognitive preference and reinforced by challenging students to consolidate their learning through other modalities has emerged from the brain-based theory as an idea that is worthy of consideration. Similarly, helping teachers to realise that often they subconsciously structure their lesson strategies in a manner that reflects their personal thinking style, without appreciating that more than three-quarters of their class may benefit from accessing the content of the lesson by using alternative modalities of learning, has major implications for curriculum planning and pedagogical development (O'Brien & White, 2010).

LESSON FIVE – CRITICAL PERIODS: WINDOWS OF OPPORTUNITY OR A PSEUDOSCIENTIFIC FAD?

Another field of neurological research that has aroused the interest of educators in professional learning sessions surrounds the concept of 'Critical Periods'. Alferink and Farmer-Dougan (2010) reported that a prominent theme in the neurobiological research over the past 30 years has been investigations into neural sculpting and the critical periods of development for sensory, language and motor skills. Early researchers postulated that animals must have certain kinds of experience at specific times in order to fully develop particular skills. By applying this reasoning to an educational setting, it is theorised that a child's peak learning occurs just as the synapses are forming (Diamond, 1998; Wolfe & Brandt, 1998). The ability to adapt and reorganise relevant stimulation was seen as crucial. Peterson (2000) spoke of a 'sensitive period' for learning. He noted children between the ages of three and 12 are capable of developing an incredible vocabulary of upwards of 100 000 words, thereby suggesting children learn about 50 new words every day.

Adding to the theoretical base, Wolfe (2010) postulated there is a critical period of neural sculpting in children between six and 12 years of age – a 'state of developmental grace' – when children learn faster, more easily and with more meaning than at other times in their lives. She suggested the critical periods are 'windows of opportunity' when the brain 'demands' certain types of input to create and consolidate neural networks. Sousa (1995) agreed and also contended that, while later learning is possible, what is learned during the 'window period' significantly affects what may be efficiently learned after the window closes. Bruer (1998) observed critical periods exist for different specific functions. For example, the critical period for phonology (learning to speak without an accent) ends in early childhood, while the acquisition of grammatical functions does not end until 16 years of age. Other commentators (Diamond, 1998) have made similar links with the teaching of music, fine motor skills and the learning of a second language.

In light of the above research, teachers were interested in workshop sessions to debate the implications of critical periods, especially with respect to the potential benefits of teaching foreign languages in early years classrooms. At this stage it appears the jury is still out on the issue of critical periods. More recently Alferink and Farmer-Dougan (2010) have argued that while there is no doubt that significant changes occur in the brain during early childhood and that young children appear to learn quickly, there is little evidence to suggest that this period is the *most critical*. They suggested early learning is important because it sets the basis for later learning, not because the window of opportunity has closed. Furthermore they cited research that indicates the development of critical and analytical skills appears to have its own critical periods as the pruning of neurological connections become more prominent.

LESSON SIX – LESS IS BETTER: THE BRAIN NEEDS A REST!

Over recent years, educators across Australia have been engaged in a series of consultations on the Australian Curriculum. A recurring theme of the workshop sessions is the view that most of the draft curriculum documents are 'top heavy' in content with respect to suggested time allocations, thereby emphasising surface learning at the expense of deeper, inquiry-based conceptual experiences.

Insights from brain theory validate the professional judgements of educators. The brain has not evolved by simply absorbing a whole array of disjointed data; it needs time to process and make sense of the experiences it is encountering (Wolfe & Brandt, 1998). While the acquisition of knowledge is directly related to the formation of new synaptic connections, 99 per cent of all sensory information is discarded almost immediately upon entering the brain, many synaptic connections are often temporary and the brain only builds and maintains the pathways that are relevant to its ongoing 'survival' (Wolfe, 2010).

Effective pedagogy requires the brain to be focused on the information that is being accessed at any particular moment. Perry (2000) drew attention to the fact that the neural system fatigues relatively quickly. Three to five minutes of sustained activity will result in the neurons becoming less responsive. He contended that, when a neuronal pathway is stimulated in a continuous, sustained manner, it is not as efficient as when it is receiving patterned, repetitive stimuli over a series of intervals. Perry furthermore noted the recovery period for neurons is also relatively brief. Consequently, if, after a short period of time, the learning is directed down an alternative pathway, more effective learning will occur. It is the interrelationship between neural systems that is vital. Students are seen to learn more completely (that is, create meaning and memory) if they weave backwards and forwards between the neural systems. If the experiences are simply familiar or repetitive, existing individual connections may be strengthened without developing new interconnections across the neuronal network that would facilitate deeper learning and understanding.

Jensen (1998) highlighted the importance of variety in the acquisition process. When a student is in a familiar, emotionally safe environment, such as the classroom, the brain will seek 'novelty' after about four to eight minutes. If variety is not provided by the nature of the learning encounter, the brain will seek alternative stimuli elsewhere. While explicit instruction is vital for learning, an over-reliance on constantly holding a student's attention with direct input negates the fact that much learning comes from indirect acquisition, notably peer discussion, structured thinking activities and environmental stimuli. The brain 'needs a rest' from formal input and drill and practice activities. In a brain-compatible classroom, teachers should only engage the learner's direct attention for 20 to 40 per cent of the time (Jensen, 1998). Specific explicit instructional processes should only occur in short bursts, relative to the age of the learner. Learning sessions should incorporate instruction, processing, encoding and, most importantly, neural rest.

LESSON SEVEN – ELABORATION: DISTINGUISHING BETWEEN PRACTICE AND REHEARSAL

Another of the 'top three' learning insights that emerged from the professional learning workshops was the concept of 'elaboration'. In brain-based learning theory, elaboration plays a crucial role in the functional development of the brain and ultimately in retention and memory. It involves the process of sorting, shifting, analysing and testing data that deepens the learning experience by strengthening the contact between the new data and the knowledge already stored in the various systems of the brain. Elaboration is an interactive process that requires feedback from a multitude of sources, notably collaboration with the peer group, digital and social media, structured thinking activities, personal reflection and teacher reaction.

In terms of pedagogical practice, elaboration distinguishes between 'practice' and 'rehearsals' in developing synaptic connections (Lowery, 1998). Practice involves the repetition of the same conceptual item over and over again, such as learning the times tables. Rehearsal, on the other hand, involves building on and extending concepts by doing something similar but not in an identical manner (for example, applying the tables in problem-solving settings or expanding the difficulty level: 22 × 2). Rehearsals reinforce learning while adding something new. Hence, practice strengthens individual neuronal pathways, while rehearsals enable the brain to develop a series of branching, interrelated pathways.

Generating learning experiences that challenge students to elaborate upon a recent learning experience is vital for memory retention. Information is easier to remember if it can be explicitly linked to something already stored in the memory bank (Jones, 1996). Each record or 'memory trace' represents a pattern of connections amongst the brain cells that can be reactivated to recreate components of the experience. According to Lowery (1998), reactivation links material involved in the experience with other characteristics of the event. When learners place an image in their mind, they store its components in many different places (for example, shapes in one place, colour in another, scent in a third). Pathways are constructed between the different storage areas and are activated when the brain endeavours to recall an experience. Elaboration activities or rehearsals of learning are required to connect the differing storage areas together in order to reconstruct the memory when it is required at a future stage. Indeed, if a concept cannot be reconstructed it cannot be said to have been learned. In terms of pedagogy, students need frequent opportunities to explicitly reconstruct and elaborate upon their learning in contrast to simply reiterating the teacher's perception of the world.

LESSON EIGHT – DISCERNING MEANING: AN ENDANGERED SPECIES OF THE LEARNING PROCESS?

In contemporary Australia, where political rhetoric, comparative school report cards and international league tables can cloud, and in some cases dominate, the educational landscape, it is crucial that teachers are constantly reminded of the main game: education is fundamentally about learning to construct meaning in its deepest and fullest sense. With the growing emphasis on objective, measurable and electronically marked test results, there is a grave danger that the importance of discerning meaning, with all of its ambiguity and subjectivity, will become a lost art, an endangered species within modern educational paradigms.

A review of the brain-based literature makes it apparent that the dominant function of the brain is to discern meaning for each individual. Concepts such as patterning, elaboration, engagement and relevance are all crucial to the learning process. Research has identified a number of key notions surrounding the manner in which the brain functions. These reveal that the brain has not evolved by absorbing meaningless data; it needs opportunities to make sense out of what it encounters; it is essentially curious and must remain so in order to survive and to function effectively; and it seeks constantly to find connections between the new and the known. In essence, brain-based theory is premised upon the innate desire of each human being to search for meaning.

Yet notwithstanding the above, when teachers in Tasmania (White, 2005) were asked to identify the criteria that should underpin and guide their pedagogical practice, only 16 per cent of workshop responses suggested processes that would nurture meaning-making (for example, connected knowing, reflection, elaboration, critical and intuitive thinking). It was apparent that, in an outcomes-based learning environment with an increasing emphasis on external testing regimens, discerning meaning may have ultimately become an endangered species in the learning cycle.

Further there is also a real danger in the contemporary standards-based environment of teacher assessment that the importance of meaning making may be underestimated. If evaluative judgements focus on the explicitly observable dimensions of teacher performance – such as the capacity to engage students and differentiate for their learning needs – in contrast to identifying the more subtle but crucially important dimension of their craft, the discernment of meaning, then supervisors may inadvertently direct teacher attention away from the most crucial element of the learning process.

One significant by-product of an interest in brain-based learning theory has been the development of a number of pedagogical frameworks that have drawn heavily, while not exclusively, from the research. The action research project in Tasmania was designed to explicitly critique one such model, the DEEP Framework (White, O'Brien & Todd, 2003). After exposure to brain-based learning theory over a three-day workshop program and its incorporation within a pedagogical model, teachers were asked to use and critically evaluate a range of high-order thinking activities in their classrooms over a period of two terms. The increased awareness and importance of meaning-making experiences were reflected in more than 75 per cent of respondents citing criteria from the 'discernment' dimension of the framework as part of their reflections upon practice, in contrast to only 16 per cent at the commencement of the study. This demonstrates that, although endangered, the importance of meaning making in pedagogical practice can be brought back from the edge of extinction through the use of frameworks that focus teacher attention on the primary goals of the learning experience.

LESSON NINE – NEURAL PLASTICITY: THE LATEST FRONTIER

As the interest in brain-based learning principles has grown around Australia, individual schools and school systems have begun exploring the potential applications of the theory to the field of special education. The concept that has garnered the most attention with teachers involved in supporting children with specific learning difficulties has been that of neural plasticity. A review of the neurological literature before the mid-1990s (Wolfe & Brandt, 1998) tended to suggest that after the initial formation of major neurological pathways in the brain, especially those responsible for connecting the various processing centres, there was little possibility for reshaping brain function in the event of major trauma, environmental deprivation or substance abuse. The theorists contended that, after birth, no further significant neuronal cells are produced and damaged cells cannot be replaced.

Conventionally, brain-based research has highlighted three phases of neuronal development. Initially, genetic coding influences neuronal formation and induces the neurons to send out pathways. As the embryo and the infant become more active, the neurons begin sending electrochemical activity down the 'wires'. Through acquisition, elaboration and encoding a stage is reached when patterned (meaning-making) activity is needed to stimulate neuronal connections and to precisely 'hard wire' the brain's response to the environment (Peterson, 2000). It was argued that the brain had to be stimulated to continually use the synaptic connections that were generated during childhood (for example, foreign language acquisition), otherwise the natural synaptic pruning that occurred during adolescence and early adulthood would discard such pathways and inhibit future learning in the nominated domain. From an educational perspective the mantra that was often invoked was the 'use it or lose it' approach: that is to say, optimal long-term brain functioning was highly dependent on being appropriately stimulated and challenged, especially in the early years, and that a failure to do so would result in an irreversible decline in cognitive functioning ability.

From a pedagogical perspective, this underlying premise has been seriously questioned in recent years. The concept of neuroplasticity, the capacity of the brain to change its structure and chemistry in response to the environment, has been a major focus of research, particularly related to the field of special education. Wolfe (2010), citing studies with visually and hearing-impaired subjects, suggested the neuronal pathways designated for sight or hearing could potentially change their initial functions in order to assist the creation of alternative pathways for auditory or tactile neuronal activity. Recent case studies reported by Doidge (2010) and Arrowsmith-Young (2012) point to the educative potential of 'retraining' the brain through a series of systematic, sustained cognitive exercises.

While research with respect to the Arrowsmith model of brain transformation is still limited, and its methodology strongly contested in the broader neurological field, an Australian-based research and development pilot program has recently been commenced by the Catholic Education Office in Sydney. The project has been designed to ascertain whether a highly intensive, personalised program that explicitly endeavours to rewire neuronal pathways will provide longer term educational and sociological benefits to a target group (initially eleven Year 9 and 10 students) for whom conventional learning paradigms have proved to be inadequate. While being undoubtedly targeted at a specific cohort of students, it is anticipated that the value in exploring this emerging frontier of research may reap significant benefits into the future.

LESSON TEN – BRAIN-BASED LEARNING: A REFLECTION OF SHARED WISDOM

Brain-based learning research, while significant, should never naively suppose that it captures or explains the many nuances of high-quality pedagogy that educational researchers and experienced teachers have discerned over many centuries. While researchers (D'Arcangelo, 1998; Peterson, 2000) have highlighted the notion that a stimulating, interactive, problem-oriented classroom environment will foster the building and pruning of neuronal capacity – regarded as crucial factors in enhancing the brain's ability to learn – educators have instinctively known this for decades. Put simply, in many cases the field of brain-based research reinforces and affirms the shared wisdom of the teaching profession, in contrast to producing major research findings that point to the development of new or enhanced classroom pedagogies.

For example, many of the pedagogical principles of cooperative learning (Johnson & Johnson, 1989; Kagan, 1994), such as the importance of scaffolded learning experiences, the significance of modelling and joint construction, the creation of an appropriate culture for social interaction and the notions of pacing and neural recovery, have all been validated by ongoing brain research. Similarly many of the pedagogical models that have been 'stimulated' by brain-based research such as whole brain thinking (Herrmann, 1988) or multiple intelligences (Gardner, 1999) owe their development to theoretical constructs that have emerged from a rather simplistic modelling of brain functioning in contrast to a sophisticated in-depth understanding of how the brain functions in reality.

The lesson in essence for pedagogical practice is one of caution and common sense. Teaching practitioners need to trust in the shared wisdom of the profession that has evolved over many generations. Brain-based learning theorists have much to offer to the teaching profession but methodologies supposedly premised on neuroscience need to be carefully analysed and rigorously researched in real-life classroom environments before entering into the body of shared knowledge that characterises an authentic learning community.

CONCLUSION

Reflecting upon the 'Decalogue of Lessons' from brain-based learning theory that have emerged from both research and lived practice has exposed some hidden gems, affirmed what many would already recognise as high-quality practice and questioned the assertions of those educators who uncritically embrace populist theories based on only a rudimentary understanding of how the brain operates. As has been revealed by the concept of neural plasticity, the rapid advances in neurological research are liable to render our 'primitive' understandings of the brain as virtually worthless in the foreseeable future. Equally, if educators do not develop a functional understanding of the brain, not only will they miss out on many useful (though not necessarily earth-shattering) pedagogical insights, they will be even more vulnerable to 'pseudoscientific fads, inappropriate generalisations and dubious programs' (Wolfe & Brandt, 1998).

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FROM BRAIN RESEARCH TO DESIGN FOR LEARNING: CONNECTING NEUROSCIENCE TO EDUCATIONAL PRACTICE

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Professor Peter Goodyear is Professor of Education at the University of Sydney. He is the founding co-director of the Centre for Research on Computer-Supported Learning and Cognition (CoCo) and now also leads the University's Sciences and Technologies of Learning research network, a multi-faculty network involving over 80 academic staff and PhD students. Before moving to Australia in 2003, Peter was Professor of Educational Research and Head of the Department of Educational Research at Lancaster University in the UK. He has also held academic positions in London, Birmingham and Belfast. In 2008, Peter was awarded a Senior Fellowship of the Australian Learning and Teaching Council and in 2010 he became an Australian Research Council Laureate Fellow – the first and so far the only Laureate Fellow working in the field of education. His current program of research – the architecture of productive learning networks – aims to strengthen the use of 'designerly ways of thinking' in education. From 1993 to 2012 he was editor in chief of *Instructional Science*, an international journal of the learning sciences. His latest books are *Epistemic fluency and professional education: Innovation, knowledgeable action and working knowledge* (with Lina Markauskaite, Springer), *The handbook of design in educational technology* (with Rose Luckin and others, Routledge) and *The architecture of productive learning networks* (with Lucila Carvalho, Routledge).

ABSTRACT

Many people who care deeply about the improvement of education believe that research ought to be able to provide some of the intellectual resources needed by practitioners and policy makers. Many people are also sceptical about the power and purpose of contemporary educational research and point to the chasms separating the producers and intended consumers of research on learning. In the last few decades, hopes have been raised, periodically, by the promise of a more scientific basis for educational theory and practice – whether through the use of computational modelling, randomised controlled trials or cognitive neuroscience. When people are anxious to find firmer ways of resolving recurrent, 'wicked' educational problems, it is not surprising if they try to push the science faster and further than it can reasonably go.

It is against this backdrop of unmet demand for robust answers that I want to examine some of the ways that educational practice can, and should, respond to insights emerging from brain research. I will develop three main arguments. First, that there are some particular areas of educational practice that offer a more congenial home for the application of research-based evidence about the brain, mind and learning – my example will be *design* for learning. Second, that brain research is inspiring some deep reconsideration of how we should conceive of *human competence* – such that a number of prevailing assumptions about assessment and curriculum will be severely tested. Third, that the increasingly complex networks of digital and other tools and resources, which are bound up in many productive human activities, also need to be understood, as part of any serious attempt to reconfigure assessment, curriculum or learning environments.

DEBUNKING THE PSEUDOSCIENCE BEHIND 'BOY BRAINS' AND 'GIRL BRAINS'

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Associate Professor Cordelia Fine has been described as a 'cognitive neuroscientist with a sharp sense of humour and an intelligent sense of reality' (*The Times*), 'a brilliant feminist critic of the neurosciences' (*Times HES*) and a 'Myth-Busting Hero' (CARE).

Cordelia's latest book, *Delusions of gender: The real science behind sex differences*, has been described as 'a welcome corrective' (*Nature*), 'carefully researched and reasoned' (*Science*) and suggested as 'required reading for every neurobiology student, if not every human being' (*PLOS Biology*). It was short-listed for the Victorian Premier's Literary Award for Non-Fiction, the Best Book of Ideas Prize (UK) and the John Llewellyn Rhys Prize for Literature (UK). Cordelia is also the author of *A mind of its own: How your brain distorts and deceives*. Cordelia is a regular contributor to the popular media, including the *New York Times*, *Wall Street Journal*, *The Monthly* and *New Statesman*.

Cordelia studied experimental psychology at Oxford University, followed by an MPhil. in criminology at Cambridge University. She was awarded a PhD in psychology (at the Institute of Cognitive Neuroscience) from University College London. She is currently an Australian Research Council Future Fellow in psychological sciences and Associate Professor at the Melbourne Business School, University of Melbourne.

ABSTRACT

A common message being sold to educators and parents these days is that brain-imaging research tells us that there are profound differences between male and female brains. Supposedly, these brain differences mean that boys and girls learn differently, and should therefore be taught in different ways or even in different classrooms and schools. But a look at the complete scientific evidence reveals that research has identified very few reliable differences between boys' and girls' brains – and none that is relevant to learning or education. Scientifically, there are three major problems with these kinds of claims made by those who propose sex-specific teaching on the basis of different brains. The first problem is that the supposed sex difference in the brain often doesn't exist. The second problem is that, even if it did exist, we would have no idea of the implications in terms of thinking, feeling or behaviour – and certainly not educational implications. The third problem is that a colourful brain-scan image showing a supposed difference between a male brain and a female brain can dazzle us so much that we overlook a very important point: boys and girls are far more similar than they are different. Psychologists have been studying gender differences for decades and decades – from maths and verbal skills to self-esteem and leadership style – and in the majority of cases differences between the sexes are either nonexistent, or so small as to be of no practical importance in an educational setting. This presentation travels through the science and pseudoscience of sex differences in the brain.

BUILDING THE REALITIES OF WORKING MEMORY AND NEURAL FUNCTIONING INTO PLANNING INSTRUCTION AND TEACHING

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Professor John Pegg is foundation Director of the SiMERR National Research Centre at the University of New England, Armidale. He is known for his contribution to theory-based cognition research, and he is recognised as a world authority on the SOLO model of cognitive development. His research interests include the development of students' and teachers' understanding and developmental growth.

He has been involved in many recent large-scale projects that linked to underachieving students in basic mathematics and literacy, state-wide diagnostic testing programs in science, developmental-based assessment and instruction, the validation of the Australian Professional Teaching Standards, the ÆSOP study investigating faculties achieving outstanding student-learning outcomes, research into teacher career stages and assessor training and applied research agendas in teacher quality in the Philippines.

He has strong links with schools, professional teaching associations and educational authorities in Australia and overseas, and has been a research consultant improving teaching practice in schools, in professional development of teachers and in syllabus development.

ABSTRACT

What are important take-home messages of a learning brain for teachers? This session considers this question, initially, by briefly focusing on the current theory constructs of working memory, long-term memory, neural connections and why evolution may have presented us with the type of brain we use today. When planning for teaching and learning the implications of these constructs need to be taken into account. But the activity of the brain does not happen in isolation of the personal, social or cultural context of the learning environment or of limitations within the brain associated with issues of cognitive load. Significantly, for optimal learning to occur, the teaching agenda should represent the reality of working memory and neural functioning. This means it is important for teachers to understand the implications of automaticity, a special kind of rehearsal referred to as deliberate practice, and the valuing of errors and the use of these errors as a source of building expertise. Alongside of this is the equally important emphasis on the role that consistent and sustained effort plays in learners achieving needed skills, knowledge and understandings.

INTRODUCTION

There are three key ideas for this paper:

- a theoretical construct of the learning brain
- neural functioning
- critical aspects of learning such as automaticity, deliberate practice and the role of errors in building expertise.

This paper describes these ideas briefly as background to the presentation.

A THEORETICAL CONSTRUCT OF THE LEARNING BRAIN

This part focuses on the current theory constructs of working memory, long-term memory, neural connections and why evolution may have presented us with the brain humans use today.

WORKING MEMORY

Working memory is a theoretical construct attributed to Baddeley (Baddeley & Hitch, 1974) and grew out of ideas associated with the workings of short-term memory. The two terms, working memory and short-term memory, are often considered synonymously but working memory is a more holistic concept associated with temporary storage of information of which short-term memory is but a part.

Working memory is not conceived as a single structure. In its current form (Baddeley, 2007) it has a central executive controlling system, two mode-specific components and a temporary memory store.

The 'central executive' part of working memory occurs mainly in the prefrontal cortex (but not uniquely as patterns of neural activity have been identified in the frontal and parietal lobes). Its functions include holding information input for a short time and also retrieving information from other parts the brain, and manipulating these aspects. The central executive system also controls two neural loops, one for visual data that activates areas near the visual cortex and is referred to as a 'visuospatial sketchpad', and one for language that uses Broca's area as a kind of inner voice, referred to as the 'phonological loop'. The temporary memory, referred to as the 'episodic buffer', holds data provided by the two neural loops, links to the central executive system and plays a critical role in conscious awareness.

In overview, working memory capacity is the brain's ability to hold information in the mind while transforming it or other information. It is where information is organised, contrasted and compared. Significantly, working memory is limited in capacity and duration. As we become more expert in a task, our working-memory size does not increase. Instead we become more efficient as our brain chunks individual aspects, enabling us to increase the information on which we can focus.

LONG-TERM MEMORY

Long-term memory is where knowledge is held. The process of laying down long-term information differs in both a structural and a functional sense from that of working memory. Permanent changes in neural networks are associated with long-term memories.

The amount of information that can be stored in long-term memory appears to be unlimited. Once information is laid in long-term memory it appears stable, although some recent research points to challenges to this idea in a small number of specific circumstances. Significantly, once strong neural connections are established in long-term memory, for most practical purposes they remain available for activation given appropriate circumstances.

While forgetting does happen to information held in long-term memory, it occurs at a slow rate and seems to depend on the amount of use and breadth of the neural connections. Forgetting is usually not about the loss or disestablishment of a neural network but that it has become increasingly difficult to access.

NEURAL NETWORKS

Numbers of single neurons (nerve cells) link together to form neural networks or pathways. Neurons are nerve cells that transmit information through an electrochemical process in which a signal using neurotransmitters is sent from one neuron over a small gap (a synaptic cleft) to receptors of another neuron that receives the information.

Our brain contains 10^{11} neurons and each neuron in the brain can link with as many as 10 000 other neurons. The brain stores information in neural networks and the existence of a memory comes about through the activation of a network of many interconnected neurons.

It was Donald Hebb who stated that if two neurons are active at the same time, the synapses between them are strengthened:

> *When an axon of cell A is near enough to excite cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased. (Hebb, 1949, p. 62)*

This quote is often referred to as Hebb's law and paraphrased as: Neurons that fire together (over time) wire together. It is saying that with repeated use, the efficiency of synapse connections increases, facilitating the more efficient passage of nerve impulses.

It was not until the 1970s that researchers identified the mechanism that supported Hebb's idea. Recent research has increased our understanding of the process of building neural networks; for example, efficiency of the connections is increased for neurons activated together and connections of a number of neurons into a single neuron enhances the strength of these connections.

EVOLUTION'S ROLE IN THE BRAIN

It has been suggested that there is an evolutionary advantage linked to the notion of a limited capacity working memory and the time and effort required to create neural networks in long-term memory.

The view here is that being able to pay attention through working memory to a limited number of aspects that were most important had a survival advantage. In the case of an attacking wild animal, selecting an appropriate action from a large number of diverse ideas would potentially interfere with the rapid decision-making needed for life preservation.

In terms of long-term memory there are also evolutionary advantages to its structure and mode of operation. The ability to lay new memories or replace old memories quickly is unlikely to be advantageous as there would be the possibility that certain fundamental and critical brain networks could be lost. This could or would render the individual at risk. Small changes occurring over time associated with effort also allow the opportunity for an individual to test the efficacy of what has been acquired.

OVERVIEW

Long-term memory is where permanent information is stored. This can be enhanced by both mental repetition of the information and by giving the ideas meaning, and associating the information with other previously acquired knowledge. Motivation is also a consideration in learning and material is more likely to be retained where there is strong learner interest.

Human intelligence comes from stored knowledge in long-term memory, not long chains of reasoning in working memory. Improved learning consists of building neural networks that either take existing networks and add further connections to them or combine separate neural networks into a larger network that can be activated holistically.

A neural network can hold large amounts of information as a simple unit in working memory. Higher order processing occurs when there is 'sufficient space' in working memory so that appropriate networks can be accessed from long-term memory and worked upon.

Through the limited capacity of working memory, the brain is designed to forget most of the data that comes through the senses. The brain does allow us to remember information that we practise and rehearse. But mere consolidation of knowledge in long-term memory does not guarantee that it will be able to be accessed indefinitely.

Storage of information into long-term memory depends on two issues. The first involves effort usually in the form of repetition or rehearsal. The second relates to storage and this works best if the material, concept or activity is understood at some level of meaningful association linked to an individual's experience.

Learning is linked to the plasticity of the neural networks in the brain. Neuroplasticity refers to the brain's ability to change by creating new or modified neural networks. This can occur by a number of ideas being found in one neural network distinguished through different patterns of neurons or by a single idea being found by the activation of different neural networks spread throughout the brain.

NEURAL FUNCTIONING

The activity of the brain does not happen in isolation of different contexts within which humans learn. Important contexts may be of a personal, social or cultural nature or of limitations within the brain associated with issues of cognitive load.

CONTEXT OF THE LEARNING ENVIRONMENT

The issue here is that learning takes place within certain contexts and these can have a huge impact on the brain and subsequently on the quality of the learning involved.

The work of Dweck (2006) offers insights into problems caused when instruction or belief systems do not support neural reality. In particular, the often-cited study where 400 fifth-grade students were praised for 'trying hard' as opposed to praising for 'innate intelligence' on a problem-solving task is most relevant.

According to Dweck, a series of experiments found that those students who were praised for intelligence (only in a single sentence) mostly chose to attempt more straightforward questions (when given a choice); showed increased stress levels on more difficult problems; and performed poorly when expected to undertake problems similar to the base-line experiment, than the group of students who were praised for their ability to work hard to solve the problems.

In follow-up interviews, Dweck found that those students who thought that intelligence was the key to success would downplay the importance of effort. Expending effort for them became a sign that they were not good enough. It also explains why those who were praised as 'intelligent' went for the more predictable questions and were less willing to take risks because they had more to lose if they failed.

COGNITIVE LOAD

George Miller in 1956 suggested that the number of bits of information that can be retained is about 7 +/– 2. This is often referred to as Miller's law. While this is often true of capable students, across the population it is probably closer to around four items (Cowan, 2001), although this can depend on context.

'Chunking' can lead to holding more information in working memory. Chunking is taking bits and combining them into more meaningful groupings (this is the reason we express phone numbers in groups of three or four as it reduces the cognitive load associated with remembering a long set of individual numbers). When chunking occurs, each new chunk becomes one of the 7 +/– 2 items.

When we talk of cognitive load in learning we are referring to the limits imposed by the finite capacity of working memory to undertake information processing and that changes to long-term memory occur slowly and incrementally. So a teacher needs to be conscious of several features including the complexity of the material to be acquired, how the material is to be presented or taught and the background experience and knowledge of the learner if optimum learning is to occur.

This last point requires further elaboration. In the case of learners acquiring new information, the limited capacity of working memory is a critical element to knowledge acquisition and places serious conditions on the learning environment.

In the case of learners working in familiar situations with organised information (in terms of elaborated schemas) laid down in long-term memory, the situation is different. For this experienced group of learners, while the number of chunks that can be retrieved to work on remains limited, the amount of material represented by a chunk can be substantial.

OVERVIEW

From a brain perspective, the notion of innate intelligence does not represent neural reality. To have information laid down in long-term memory requires at the very least practice, rehearsal and effort.

An important aim of teaching is to assist students to reduce the cognitive load associated with basic and routine tasks to facilitate deeper higher-order understandings. There are large processing demands associated with inefficient methods (such as finger counting or word decoding strategies), as opposed to direct retrieval approaches.

Learning is about establishing neural networks. Those networks where neurotransmitters can send nerve impulses efficiently between neurons results in improved memory recall and use. Further, in committing something to memory, just as in most other activities, how the material to be learned is organised is important. Understanding assists the brain with such organisation.

CRITICAL ASPECTS OF LEARNING

This part considers three critical aspects of learning related to the brain. These are automaticity; deliberate practice; and the valuing of errors and their use as a source of building expertise.

AUTOMATICITY

Automaticity is the ability to complete everyday tasks effortlessly without requiring conscious effort. In learning, automaticity becomes important when considering the acquisition and use of low-level or fundamental skills and higher order or advanced concepts.

In the case of lower order skills, automaticity frees up working-memory capacity. This involves a change in the neural networks activated, and an overall lessening of brain activity. In the case of higher order skills, more complex information takes a heavy toll on working-memory capacity. Given the limits of working-memory capacity it is critical that needed 'space' is not used up on basic tasks that preclude the brain from accessing or processing more advanced ideas. Hence, an important goal of education is not to distract the learning brain by an overemphasis on basic skills that should be automated.

In summary, with high consistency of processing speed and accuracy of responses, foundation skills can become automatic. As a result, more cognitive effort can be devoted to higher-order skills.

DELIBERATE PRACTICE

A special kind of rehearsal is referred to as deliberate practice. Much of the early work in this area is attributable to a study by Eriksson, Krampe and Tesch-Romer (1993).

Deliberate practice is an activity that is well structured and designed to improve the current level of performance. As the name suggests, it allows for repeated experiences in which the individual can attend to critical aspects of a task.

Within deliberate practice, specific activities are used to deal with identified errors or weaknesses within a context of feedback. People are motivated to exert effort on particular aspects of a task because the focused practice on these key aspects improves overall performance.

VALUING ERRORS

Errors play a critical role in the establishment and maintenance of neural networks and, consequently, in building expertise. There is an evolutionary take on this aspect that the brain appears to be especially organised to respond to mistakes in a 'positive' way in terms of learning outcomes.

Those ancestors who did take notice of incorrect decisions and changed their behaviour would have been more likely to survive. Hence one could envisage that incorporating lessons from the past into our future decision making was an important characteristic to acquire. The alternative, of course, is that one would continue to repeat past errors.

If we do not allow students in schools to experience the significance of the role errors and mistakes play in learning then we are setting them up for future failure as well as placing a ceiling on their learning. Learning from mistakes is how learners are challenged to do and look at things differently, and errors motivate the brain to try new approaches. Engaging in mistakes provides the environment for students to move to a deeper level of understanding.

Niels Bohr, the famous Danish physicist (1885–1962), once said 'an expert is a person who has made all the mistakes that can be made in a very narrow field'. The implication from this quote is that experts not only expect and accept mistakes, they seek them out to enhance their knowledge and understanding.

Success should not be measured by the number of times a learner has avoided mistakes but rather on the mastery of complex and important ideas. Education systems should not be seen as punishers of errors: such an approach does not represent the neural reality of learning. Rather, learning should be about acknowledging the critical importance of focusing on mistakes or errors and the value of educational risk taking where an error or mistake is a likely outcome.

CONCLUSION

That consistent and sustained effort plays a critical role in learners achieving needed skills, knowledge and understandings is an important message underpinning the ideas in this paper.

Working-memory capacity underlies a number of the problems students experience in acquiring competence or undertaking more difficult tasks. A critical step in supporting students is to provide them with experiences that enable them to reduce the cognitive load associated with processing basic skills so as to make way for higher order processing.

If teachers support students to replace effortful (high cognitive load) strategies with more strategic and less demanding approaches then their performances in learning will improve. All learning is also enhanced when children are encouraged to understand that making mistakes is a critical element for the brain in acquiring genuine understanding, knowledge and skills.

Evidence for the ideas expressed in this paper can be seen in the QuickSmart Numeracy and Literacy programs. These two programs draw heavily on ideas associated with the limits of working memory, the creation of strong neural networks, the valuing of mistakes and educational risk taking and motivation built on success in learning as setting the basis for higher-order skill and knowledge growth. Each year many thousands of students in schools throughout Australia undertake this program and experience substantial and sustained improvement on independent tests (for more information see http://www.une.edu.au/simerr/quicksmart/pages/).

By considering instruction through the constructs of a learning brain and, in particular, by building the realities of working memory and neural functioning into planning instruction and teaching, there is a real hope of genuine improvements in student learning. There is also the potential to have statements concerning 'students achieving their potential' to be more than just a glib mantra.

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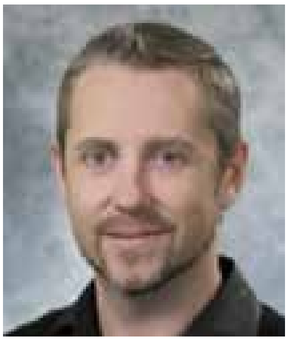
FROM THE LABORATORY TO THE CLASSROOM:

TRANSLATING THE LEARNING SCIENCES FOR USE IN TECHNOLOGY-ENHANCED LEARNING



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Dr Jason Lodge is a psychological scientist and lecturer in technology-enhanced learning at the Griffith Institute for Higher Education, Griffith University, Brisbane. Jason's research concentrates on the application of the learning sciences to education. Specifically, he is interested in the cognitive and emotional factors that influence learning and behaviour and how research findings from the learning sciences can be better used to enhance instructional design, teaching practice and education policy. Jason is also interested in the ways technology is influencing learning, particularly in terms of the impact of technology on the development of metacognition, critical thinking and expertise. Jason is a team member on a national Office of Learning and Teaching project; he is the chair of the Queensland branch of the Higher Education Research and Development Society of Australasia and is currently serving as a member of the New Media Consortium Horizon Project Australasia Advisory Board.

ABSTRACT

The learning sciences including neuroscience and cognitive psychology provide abundant opportunities for enhancing teaching, particularly as technology plays a greater role in education. But the translation of research conducted in the laboratory for use in the physical or virtual classroom is difficult. Studies examining the mind and brain cannot be easily converted into simple formulae or algorithms for learning. What is required is translation through a network of enabling disciplines for supporting teachers to enhance student learning, as it enables medical practitioners to improve health. The aim of this presentation is to outline the possibilities for the use of the learning sciences for enhancing learning with technology. In doing so, examples of the use of principles developed in the learning sciences applied to teaching practice will be explored. It is hoped that these examples will help teachers and learning scientists to understand what is required to translate research into technology-enhanced learning and teaching practice.

The evidence underpinning teaching practices at all levels of education has come under increasing scrutiny for several decades. The foundations of teaching practice have been described by Slavin (2008, p. 5) as 'driven more by ideology, faddism, politics and marketing than evidence'. While Slavin's commentary represents one end of the spectrum of criticism of educational research and is not representative of all views, this scrutiny has nonetheless prompted policy responses in a number of countries. For example, the 'No Child Left Behind' policy of the US government (US Department of Education, 2001) in the early 2000s contained within it a concerted push for what became known as the 'what works' agenda. A similar policy discussion paper has recently been issued by the Department of Education in the UK (Goldacre, 2013). The theme in both of these policy documents is similar: that education should be informed by rigorous scientific evidence including randomised control trials.

The alternative viewpoint to the criticism of current educational research and the resulting policies is that the rigorous approaches such as those used in cognitive psychology and neuroscience are too rigid and reductionist for practical use (Oliver & Conole, 2003; Smeyers & Depaepe, 2013). In other words, what happens in a laboratory or randomised control trial is not necessarily indicative of or generalisable to a physical or virtual classroom. The upshot of the debate about the 'what works' agenda is that rigorous studies examining fundamental learning processes are very difficult to translate so that teachers are able to use the findings in practice. Reeves (2011) suggested that getting the maximum benefit from research into learning and teaching will only occur when the difficult balance between rigour and relevance is achieved. This remains one of the major ongoing challenges for educational research: laboratory and imaging studies are simply not readily applicable to teaching practice without substantial translation and interpretation.

While debates about the virtues of rigour and relevance for teaching have continued, advances in technology have fundamentally altered learning and teaching at every level of education. The last decade in particular has seen an explosion in availability, power and capacity of digital technologies that have outpaced the development of effective pedagogy for using these new tools (Beetham & Sharpe, 2013). At the same time, research on the use of educational technology has faced criticism for failing to inform the implementation and development of technologies for learning in education and beyond. Selwyn (2012, p. 1) argued that 'educational technology certainly suffers from a lack of rigorous and sustained inter-disciplinary exchange' and as a field of research has therefore become overly insular, providing little of use outside the educational technology community. It would appear that although educational technology has had an increasing impact in the classroom and beyond, research into the ways in which technology can be used to effectively enhance learning has not kept pace.

The distance between rigour and relevance in educational research, educational technology and teaching practice is a fundamental issue for enhancing education at all levels. Bruer (1997) famously argued that the gap between studies examining the brain and educational practice is a 'bridge too far'. While there may never be a simple process for translating highly controlled experimental or imaging studies to classrooms, there might be possibilities for learning from other disciplines and industries where such a leap has been made. The most obvious case of basic research developing a comprehensive evidence base applied successfully to practice is in medicine (Goldacre, 2013). Chemistry and biological science, among other enabling disciplines, are translated for use by biomedical science, which is then developed into evidence-based treatments for use by medical practitioners. The ecosystem of enabling disciplines in medicine provides one way of understanding what is possibly lacking in the quest to enable teachers with a rigorous scientific evidence base.

For technology-enhanced learning, the situation is made more complex in that there remain many unanswered questions about the effectiveness of using technology as opposed to more traditional learning and teaching approaches (Selwyn, 2011). Another allegory may be useful in understanding and enabling technology-enhanced learning, that of molecular gastronomy. Although cooking, as a practice, has existed for millennia, it has only been for the last few decades that food science has had a major impact on established cuisines and traditional cooking approaches (Vega & Ubbink, 2008). Rather than force a complete rethink of the way that food is prepared, molecular gastronomy has involved a deconstruction of techniques and a tweaking of these approaches through test kitchens or laboratories relying on food science to inform incremental improvements in cooking practices (This, 2006). In a similar manner, it is possible that technology-enhanced learning could be enriched through a process of deconstructing established approaches to instruction and educational design, rapid prototyping and small-scale, rigorous testing before innovations based on the learning sciences are applied to classrooms (see also Reeves, McKenney & Herrington, 2011).

While examples of overcoming the gap between rigour and relevance are uncommon, there are some cases where a deconstruction of technology-enhanced instructional approaches has occurred. For the purpose of this paper, I will discuss these examples as 'easy' or 'hard' problems. Easy problems are those that lend themselves to relatively straightforward solutions provided by the learning sciences. One example of this is provided by Smyth and Lodge (2012). In this case, the problem was a pastoral care (that is, co-curricular) issue. When students first begin university, many feel overwhelmed with the amount of information they are asked to deal with (Kift, 2008). Sweller's (1988) cognitive load model provides a suitable approach for understanding this issue. In this case, the information provided electronically to students about admission, enrolment, financing their studies and so on is mostly essential, so there is high intrinsic cognitive load (Sweller, 1994). The approach taken by Smyth and Lodge was to reduce this cognitive load by making the orientation process 'longer and thinner' through the creation of an online portal for vital information that is self-paced and can be completed in a time frame that allows students control over when and how they consume the information. The design of the site was also based on principles of visual attention (for example, Wolfe, 1998) so, not only was the information presented in smaller chunks to reduce cognitive load, visual cues were added to guide attention to relevant important information. Sections of the site were also colour-coded to allow a simple visual indication of progress through the site. Students to whom a pilot of the site was made available used the site extensively and the number of enquiries these students had after completing the orientation were fewer than those who had completed a more traditional orientation. It would appear that cognitive load theory and principles gleaned from rigorous research on visual attention were useful in dealing with a co-curricular issue through a deconstruction of the approaches being used.

As opposed to easy problems, hard problems are those that require a deconstruction of a broader pedagogical approach or problem. Understandably, there are fewer examples of curriculum deconstruction in the literature. The example of a co-curricular problem described above in molecular gastronomy terms is akin to deconstructing one element of a dish. On the other hand, deconstructing a curriculum to increase the chances of students meeting an intended learning outcome is like attempting to deconstruct an entire dining experience of several courses including the environment in which the meal is consumed. The context in which the learning experience takes place, the nature of the students in the physical or virtual classroom and the limitations and affordances of any technology being used, among other factors, are all essential elements to consider if any enhancement is to be effective (see also Goodyear, 2005).

One way in which I have explored a pedagogical problem at the level of intended learning outcomes is the way in which academics are introduced to technology-enhanced learning in a graduate certificate program in higher education. One of the main intended learning outcomes of the technology-enhanced learning unit within this program is for students (that is, academic staff of the university) to understand the issues faced by students as they attempt to develop the literacies required to be successful in programs or units that use online or blended learning approaches. The pedagogical principle underpinning the approach used to achieve this learning outcome is experiential learning (Kolb, 1984). Despite the solid theoretical grounding behind the approach being used to help academics meet this outcome, many have not gained a grounded understanding of the difficulties faced by students adapting to online and blended learning and hence do not completely understand the importance of educational design in this context.

In order to overcome this problem, possible solutions provided by the learning sciences were considered. One phenomenon that has been researched extensively in psychology laboratories and might prove useful in this situation is 'desirable difficulties' (Bjork, 1994). Desirable difficulties are deliberate strategies for disrupting the learning process and making the learning situation more challenging. For example, Diemand-Yauman, Oppenheimer and Vaughan (2011) found that presenting participants with material in a 'disfluent' or hard-to-read font was enough to create additional 'cognitive burdens' that result in improved learning compared to when material is presented in familiar fonts. Applying the notion of a desirable difficulty to a live classroom setting is difficult as the focus of studies of the effect is low-level cognitive processes, not high-level subjective experiences of learning. In a recent study Carpenter, Wilford, Kornell and Mullaney (in press) found that, while a more fluent instructional video (that is, clear and easy to process) led to more confidence that the material had been learned, there was no difference in performance between groups exposed to a fluent or disfluent (that is, difficult to process) video. While it is therefore challenging to directly translate desirable difficulties research to the classroom, these studies provide clues as to the ways in which teaching practice can be tweaked to create conditions more likely to result in students meeting desired learning outcomes.

In the case of experiential learning for academics, desirable difficulties do not provide a straightforward enhancement but the idea that making a learning experience more difficult or disfluent to improve learning does allude to a possible solution when incorporated into established approaches. The traditional design of transformative learning experiences often involves the idea of 'scaffolding' (Pea, 2004) in that support is provided so that students are able to construct their knowledge incrementally in alignment with Vygotsky's (1978) notion of the zone of proximal development. Alternatively, the notion that more challenging learning experiences can lead to better outcomes suggests that there may be some benefit in deliberately removing some of the scaffolding. In this case, a form of 'experiential disfluency' (as per Carpenter et al., in press), as opposed to low-level cognitive disfluency (as per Diemand-Yauman et al., 2011), was hypothesised to lead to a greater likelihood that the learning outcome would be met with better retention of the learning over the longer term. The feedback from academics completing the unit suggests that, although they found the experience of being an online student difficult and at times frustrating, they had a deeper appreciation of what it takes to design effective technology-enhanced learning as a result. While the results of this tweaking of the unit using principles from the learning sciences requires further investigation, it remains plausible that a translation of the notion of desirable difficulties to an experiential situation might have helped consolidate learning in this case.

Teachers cannot simply translate research conducted into low-level cognition and brain processes for use in real-life physical or virtual classroom settings but the two examples discussed here do give an indication as to possible avenues for allowing this type of translation to occur. Research on visual attention and desirable difficulties is predominantly conducted in highly controlled laboratory settings. While these sorts of studies emulate those found in the 'hard sciences' such as physics and chemistry, the process of attempting to apply this research beyond the laboratory requires a level of deconstruction, translation and interpretation similar to that in medicine and now common when chefs in the world's top restaurants apply food science to modern cookery. Translating the learning sciences will require a level of cooperation between neuroscientists, cognitive and educational psychologists, instructional designers, educational technologists and teachers beyond what is currently common. If the rapid growth of molecular gastronomy is any indication, should this collaboration be successful, the opportunities for advancing education at all levels through technology-enhanced learning will be both countless and potentially revolutionary.

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LEARNING AND FEARING MATHEMATICS: INSIGHTS FROM PSYCHOLOGY AND NEUROSCIENCE

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Dr Sarah Buckley is a Research Fellow at ACER. Her PhD in psychology investigated adolescents' mathematics anxiety and the role that motivation and peer networks have in its development. The project drew on diverse theories including those from psychophysiology, cognitive and social psychology and social network approaches. Sarah was invited to present her work at national and international conferences and in 2008 won the AARE's Australian Postgraduate Student Travel Award. In 2012, Sarah was asked to write an opinion article for *The Age* newspaper on the phenomenon of mathematics anxiety.

Sarah is a member of the National Surveys team at ACER and has contributed to a range of projects such as the Programme for International Student Assessment and the Trends in International Mathematics and Science Study. Sarah has also been part of several projects focused on Indigenous education including the Longitudinal Study of Indigenous Children.

In addition to her time at ACER, Sarah has worked as a data analyst for the education department at Monash University and as a research assistant and tutor in the psychology department at the University of Melbourne. Sarah also has three years experience working as a teacher's aide in high school classrooms.

KATE REID

Dr Kate Reid is a Research Fellow at ACER. She completed her master's degree in psychology and PhD at the University of Melbourne, undertaking research into mathematical reasoning among preschool children. Her research applied an individual differences perspective to understanding learning processes in the acquisition of early number and measurement concepts. Through her research, she gained extensive experience in a range of early childhood settings, designing mathematics activities and interviewing children aged 3–6 years.

Kate has diverse research experiences, including quantitative and qualitative research projects for evaluations of government initiatives and community-based programs, and has published academic research in the area of higher education. Kate has extensive experience in research and teaching in higher education, having taught at undergraduate and postgraduate level in developmental and cognitive psychology, statistics and organisational behaviour.

Since joining ACER, Kate has continued her interest in the learning of preschool children through her work on the ACER research project, Longitudinal Literacy and Numeracy Study: Transitions from Preschool to School. She developed and trialled for this project numeracy activities suitable for five-year-old children, and was involved in the national implementation of the project in late 2012. Most recently, Kate undertook a review of effective approaches to numeracy intervention among children in the early years of schooling.

ABSTRACT

Researchers investigating mathematical development do so from different perspectives. Disciplines such as education, psychology and neuroscience have focused on mathematical learning and motivation, but research in these fields has tended to be conducted independently. Although different research strategies and methodologies are employed in each discipline, similar research questions inform these approaches and findings from these areas are complementary. In this session, we consider two examples from the field of research on mathematical development and present some relevant research developments from psychology and neuroscience. Our first example focuses on how very young children begin to acquire mathematics concepts. In our second example, we discuss the phenomenon of mathematics anxiety and its impact on children's learning of mathematics. Our overarching goal is to illustrate how findings from psychology and neuroscience may be used to better understand the processes underlying children's learning of mathematics, and to suggest how these findings might be applicable to mathematical behaviour in the classroom.

INTRODUCTION

There is much interest in the potential for neuroscience research findings to significantly affect classroom practice. Some researchers argue that direct application of neuroscience findings to educational practice is difficult because our understanding of the brain and brain development is still fragmentary (Bruer, 1997) but considerable interest remains in the field of education in how findings from neuroscience might inform teaching. If research findings are to be applied, they must be critically evaluated. Educational practitioners need some assurances that robust research evidence underlies teaching practices and programs derived from neuroscience findings.

In this session, we argue, in line with Bruer (1997), that cognitive psychology is the field that connects the application of neuroscience findings to the field of education. Furthermore, we provide evidence of how an interdisciplinary approach could be used to understand learning in mathematics. There is evidence of cross-field integration in describing children's early mathematical development, and proposing and testing models of mathematical cognitive development from infancy to the early years of primary school. Findings from different disciplines have also been applied to understanding barriers to school-based learning, which includes the phenomenon of mathematics anxiety, commonly reported by secondary school students. Discussion of these two related areas is intended to demonstrate the contribution that education, cognitive psychology and neuroscience together can make to informing teaching practice and interventions in mathematics.

EARLY NUMERICAL ABILITIES AND DEVELOPING NUMBER SENSE

There is considerable evidence that the ability to understand simple number relationships is early developing, or even innate (McCrink & Wynn, 2004; Wynn, 1990, 1992a, 1992b, 1995). Studies of infants imply that they may have a preliminary understanding of cardinal relationships (concepts of the number of objects) (Antell & Keating, 1983; Starkey & Cooper, 1980; Starkey, Spelke & Gelman, 1990) and of transformations to numbers (Wynn, 1992c, 1992d, 1995). These abilities were thought to be limited to very small numbers (up to three or four), but more recent evidence suggests that infants are also sensitive to the results of large number transformations, which may reflect an approximate number system. Evidence of a pre-verbal number sense among human infants and animals implies that mathematical competence is initially independent of language. Number sense skills include an ability to rapidly identify small numbers, recognise number order, reason about simple transformations (for example, adding and subtracting one), exhibit counting skills and apply counting to solve number problems. Number sense capabilities are related to achievement in school (Bisanz, Sherman, Rasmussen & Ho, 2005; Mix, Huttenlocher & Levine, 2002), but there is significant individual variation in the development of children's number sense before school, and evidence that some children find it difficult to connect informal knowledge with school mathematics (see, for instance, Carraher, Carraher & Schliemann, 1985; Carraher & Schliemann, 2002; Nunes, Schliemann & Carraher, 1993).

Among preschool children there is similar evidence for early informal understanding of number concepts for both small and large sets of objects that is independent of the development of counting (Canobi & Bethune, 2008; Slaughter, Kamppi & Paynter, 2006). Gelman and colleagues' extensive research on counting development suggests that understanding the principles of counting guides children's whole number development (Gallistel & Gelman, 1992; Gelman, 2000). Evidence of principled understanding is thought to be evident in children's capacity to detect violations of the counting principles, even when they cannot count (Gelman, 1980; Gelman & Gallistel, 1978; Gelman & Meck, 1983, 1986; Gelman, Meck & Merkin, 1986).

This brief description of key research in mathematics has implications for early mathematical learning. It is argued that humans possess specialised mechanisms for processing information about numbers. A specific mechanism for discrete number suggests that difficulties could arise in extending learning from whole number concepts to those involving rational numbers. From a psychological perspective, early reasoning about fractions is difficult because it is incongruent with a system supporting natural number development (Gallistel & Gelman, 1992; Gelman & Meck, 1992; Hunting & Davis, 1991; Mack, 1995; Sophian, Garyantes & Chang, 1997). This conflict is evident in students' extension of whole number principles to fraction reasoning (for example, believing ¼ is bigger than ⅓ because the denominators are compared as whole numbers).

Neuroscience and neuropsychological findings suggest that both specialised systems for processing number and separable systems for processing small and large numbers can be independently impaired (Feigenson, Dehaene & Spelke, 2004; Hyde & Spelke, 2009). The intraparietal sulcus, which shows activation in numerical estimation tasks, is believed to be the location of the approximate number system (Feigenson et al., 2004). Although much of this work to date has been conducted with adults, more recent research using minimally invasive techniques (such as EEG) with infants also suggests independent systems for small and large numbers (see, for instance, Hyde & Spelke, 2011).

Much of the evidence discussed supports the proposition of a number sense system from which mathematics develops. Dehaene (2001) argued that number sense has a specific cerebral location (the intraparietal cortex of both the left and the right hemispheres), but that this area is a part of a complex distributed system of connections for processing number. Specific patterns of activation depend on the mathematical activity involved (for instance, calculation versus numerical comparison) (Dehaene, Molko, Cohen & Wilson, 2004). Number sense is of interest as a critical feature of normal mathematics learning, and as a probable source of deficit for those with more severe mathematical difficulties (Gersten & Chard, 1999). Children with dyscalculia, for instance, evidence structural and functional deficits of the intraparietal sulcus (Dehaene et al., 2004). Though any deficiencies in initial number sense may constrain early learning, these limits are not fixed. Training in mathematics problems is associated with pronounced changes in patterns of brain activation and corresponds with variation in behavioural data (such as reduced reaction time and higher accuracy) (Zamarian, Ischebeck & Delazer, 2009). Moreover, different learning methods (learning by rote versus learning strategically) result in different patterns of brain activation (Delazer et al., 2005). Supplemented with behavioural data on better performance in strategic learning conditions, these data provide evidence that different teaching methods for mathematics lead to distinct behavioural and structural outcomes.

BARRIERS TO DEVELOPING MATHEMATICAL PROFICIENCY: MATHEMATICS ANXIETY

A significant barrier to learning in the mathematics classroom is anxiety. Anxiety is a widespread emotion in schools and in the community, is negatively associated with school achievement and is exacerbated by a negative culture surrounding mathematics (Ashcraft & Ridley, 2005; Hembree, 1990; Ma, 1999; Ma & Xu, 2004; Meece, Wigfield & Eccles, 1990; Wilkins, 2000). Some theorists suggest that mathematics anxiety is a consequence of struggling with poor mathematics ability (Ashcraft & Kirk, 2001). There is evidence that students who have dyscalculia report high levels of mathematics anxiety (Rubinsten & Tannock, 2010) but research has shown that anxiety can affect learning in two broad ways. Firstly, at the state or on-task level, mathematics anxiety can impair performance; secondly, as a trait, it can act like an attitude, directing students away from participation in activities and career pathways that involve mathematics.

Psychology and neuroscience provide models of the state-based effects of anxiety. According to psychological theory, a primitive biological system – the autonomic fight-or-flight response – is at the centre of the experience of anxiety and primes the body for action in threatening situations (LeDoux, 1996). Mathematics provides a threatening situation for students who report high levels of mathematics anxiety. Psychology also offers a way to understand how certain situations can evoke anxiety in one student and not in another. Izard (2007) proposed that *emotion schemas*, or 'complex emotion-cognition-action systems', are key components of the motivation and regulation of emotions and are activated when an individual appraises a situation (p. 265). These schemas are shaped by previous experiences and cultural factors. Cognitive psychology also highlights the role of *attentional biases* in making an anxious individual hyper-vigilant to threatening stimuli (Hofmann, Ellard & Siegle, 2012).

These concepts have been integrated with neuroscience research. Studies have shown that attentional biases to threatening information are activated just milliseconds after stimuli are presented and are associated with more activation in the amygdala (a part of the brain thought to be involved in processing negative emotions), and a diminished role of the prefrontal cortex (which helps to regulate emotional responses and inhibit fear-based reactions) (Bishop, 2007; Young, Wu & Menon, 2012). Recently, Young, Wu and Menon (2012) found this type of neural activation pattern in mathematically anxious children as young as seven. Together these findings suggest that mathematics anxiety predisposes students to be hypersensitive to mathematical stimuli, to experience fear almost automatically after they encounter mathematics and to be less capable of recruiting strategies to control this fear. The long-term implication of this process is students will learn to avoid situations that involve mathematics.

Evidence that mathematics anxiety has a direct or on-task effect on performance can also be found in cognitive psychology and neuroscience research. Ashcraft and Kirk (2001) proposed an online mathematics anxiety model wherein intrusive, negative thoughts about performance disrupt cognitive functioning by interfering with working memory processes. Several studies examining the effects of mathematics anxiety on working memory support Ashcraft and Kirk's model (Beilock, Kulp, Holt & Carr, 2004; Hopko, Ashcraft, Gute, Ruggiero & Lewis, 1998; Hopko, McNeil, Gleason & Rabalais, 2002; Kellogg, Hopko & Ashcraft, 1999). Furthermore, Lyons and Beilock (2012) demonstrated that the disruption of working memory processes was associated with more activation in a network of the inferior fronto-parietal regions of the brain. They proposed that their findings point to 'educational interventions which emphasise the control of negative emotional responses to math stimuli' (p. 2109).

These studies from cognitive psychology and neuroscience illustrate how mathematics anxiety operates at the state level but they do less to explain the origins and development of anxiety. If interventions to reduce anxiety must help students to control their emotional reaction to mathematics, the factors that lead to children feeling negatively towards the subject must be identified. Educational and social psychology research provides more insights into the aetiology of anxiety. Cemen (1987) proposed that mathematics anxiety is a product of dispositional, environmental and situational forces. Dispositional factors can be thought of as what the student brings to the classroom. Important antecedents that are considered to be external to the student are environmental, such as teachers and peers, and more immediate, situational forces, such as the specific features of a mathematics task (Baloglu & Kocak, 2006). The focus here will be on the role of teachers, peers and gender socialisation as environmental and situational forces that operate in the classroom.

Research supports the notion that the development of mathematics anxiety is influenced by multiple factors. Studies have found that a high proportion of preservice mathematics teachers report elevated levels of anxiety, with more anxious female teachers more likely to have students with lower achievement and negative gender stereotypes about mathematics (Beilock, Gunderson, Ramirez & Levine, 2010; Hembree, 1990; Uusimaki & Kidman, 2004). Frenzel, Pekrun and Goetz (2007) showed that peer esteem, measured by items such as *'most of the students in my class think mathematics is cool'* was negatively related to anxiety; students who believed that their classroom reflected a negative peer culture towards mathematics reported higher levels of mathematics anxiety. These results suggest that the role of socialisation in the development of students' mathematics identity is important, a process also emphasised in research targeting the relationship between gender and mathematics. In particular, the effect of negative stereotypes (referred to as *stereotype threat*) has been suggested as an explanation for girls' under-representation in mathematics fields and gender differences in mathematics anxiety (Tomasetto, Romana Alparone & Cadinu, 2011). National results from the 2003 Programme for International Student Assessment (PISA – Thomson, Creswell & De Bortoli, 2004) showed that Australian 15-year-old girls reported higher mathematics anxiety levels than males. Furthermore, a New South Wales study showed that the number of girls choosing to enrol in mathematics in their final years of schooling was declining at a faster rate than boys (Mack & Walsh, 2013).

These findings in relation to gender, peers and teachers suggest directions for intervention strategies. They reveal that classroom culture has the potential to influence the development of mathematics anxiety and dealing with these factors could improve students' attitude and thus achievement in mathematics. Challenging gender stereotypes and negative peer culture within the classroom are some examples of ways to move in this direction. From this type of intervention, students can develop more control over their negative emotional reactions to mathematics and inhibit the negative influence of anxiety on performance and career choices.

CONCLUSIONS

With increased interest in neuroscience findings, researchers from related disciplines have begun to supplement existing knowledge about learning with findings from neuroscience. This brief review has illustrated how existing research from education, psychology and neuroscience can provide a basis for better understanding children's learning of mathematics. Using children's early number sense and mathematics anxiety as examples, we have argued that psychology, in particular, provides frameworks for integrating neuroscience and education research. This type of interdisciplinary approach can suggest strategies for both improving mathematical learning among young children and providing interventions when students' achievement in mathematics is not as expected.

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HIGH-ABILITY LEARNING AND BRAIN PROCESSES:
HOW NEUROSCIENCE CAN HELP US TO UNDERSTAND HOW GIFTED AND TALENTED STUDENTS LEARN AND THE IMPLICATIONS FOR TEACHING

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ABSTRACT

Gifted and talented learners understand, think and know in ways that differ qualitatively from how regular learners perform these activities. Recent research that has examined the neuropsychological processes engaged by these learners provides insights into how they process information, convert it to knowledge and make links. It also assists in understanding the creative activity they display. These findings, in turn, assist in understanding how these students learn and think and how they can be taught.

This discussion reviews this research and links it with an explicit model of gifted and talented learning. The review helps teachers and schools understand what gifted and talented learning, in its multiple forms, 'looks like' or how it is displayed in regular classrooms. The discussion also identifies implications for identifying gifted and talented learning and for teaching these students. It focuses particularly on recommendations for implementing pedagogic and curriculum differentiation.

The phenomenon of giftedness is usually associated with high-level outcomes, whether on a measure of general ability, responses to achievement task, a performance or a production. The focus of this session is on the thinking and knowing that leads to these outcomes.

The context for this session is the classroom. Its perspective is the set of learning–teaching interactions that lead to the gifted outcomes. It is in these interactions that links with brain processing are more visible, as long as educators can recognise and interpret them.

This presentation begins by describing typical interpretations made by gifted students in a regular mathematics lesson. It unpacks these interpretations in terms of the learning and thinking processes that were implicated. It then links these outcomes with recent investigations of the neuropsychological processes associated with gifted learning. It concludes by examining implications for pedagogic and curriculum differentiation.

WHAT HIGH-ABILITY LEARNING LOOKS LIKE IN THE CLASSROOM: AN ANECDOTE

A Year 9 maths teacher introduces her students to Pythagoras, to the idea that the area of the square on one side of right-angled triangles (the hypotenuse) is equal to the addition of the area of the squares on the other two sides. They learn this as a formula, for example, $c^2 = a^2 + b^2$, and use it to calculate the length of the sides in triangles of this type.

This teacher asked: 'Did anyone think of ideas about this that I haven't mentioned?' Anna, without directed teaching, speculated about joined right-angled triangles in building construction, architecture and civil engineering, for example, in the triangular struts in girders holding up bridges. 'Are these triangles somehow stronger than squares or other types of triangles?', she asked. Con looked at curved surfaces in the classroom and wondered whether Pythagoras holds on curved, wavy or three-dimensional surfaces.

In another class, Gus reflected on the whole number triplets that are described by $c^2 = a^2 + b^2$ – for example, 3, 4 and 5, or 12, 5 and 13 – and wondered what the special pattern is between these numbers. He asked whether the tetruplet relationship $d^2 = a^2 + b^2 + c^2$ existed and whether there are sets of 4 whole numbers that satisfy it. He asked: 'What the sum of four squares would look like spatially?' Toni imagined a cube on each side of a right-angled triangle instead of squares and questioned whether $c^3 = a^3 + b^3$ would hold for some whole numbers and what this might look like spatially. She recalled rational numbers: 'Are the fractions that fit the pattern only those that comprise the whole number triplets or tetruplets?'

Other students learn Pythagoras very rapidly, after one or two examples only, and are ready to use it to solve more difficult tasks. Through guided dialogue and teaching, they extend their understanding of Pythagoras to more two- and three-dimensional word problems. They depend on the explicit teaching but can extend, apply or 'stretch' the taught understanding.

DESCRIBING THE UNDERSTANDING OF THESE STUDENTS IN REGULAR CLASSROOMS

To explain high-ability knowing and thinking, we need to focus on the specific 'meaning units' that comprise the knowledge of these students at any time. These units are linked in networks. When we detect information, some of our networks are 'lit up' or stimulated and we use them to comprehend the information, think about it and to respond to it.

Learning is about linking the meaning units in novel ways. This perspective helps us 'get inside students' heads' and speculate about how they make these links. It gives us tools for examining how students link the ideas they are learning at any time.

The gifted students above generated more elaborated and differentiated networks of meanings. Their class peers learnt essentially what the information taught; in right-angled triangles a particular relationship existed between the sides. They constructed meaning networks that represented this. They internalised the teaching information and formed an essentially literal understanding of it. Their links basically matched those in the information.

Anna, Gus and Toni formed an understanding that was more comprehensive than what was in the teaching information. They generated spontaneously interpretations about Pythagoras during the lesson that were more comprehensive.

The interpretations formed by the gifted students here comprised both links from the teaching and links they formed independently. They extended ideas in the taught understanding. They saw the taught ideas as parts of patterns and linked them with other aspects of what they knew. They inferred links and formed intuitions or suppositions that were unique to them, a phenomenon also noted by Robinson and Clinkenbeard (2008). The average learner may infer and extend spontaneously beyond the teaching but their inferences are usually lower level.

The gifted students' understanding was organised into a personal intuitive theory about Pythagoras. They inferred patterns from the information and then inferred a 'big idea' that synthesised the patterns. They could ask questions about their understanding and could generate ways of testing the new idea-links. They differed in the personal theories they formed. Their broader, more extensive, 'enlarged and enriched' meaning networks allowed them to understand the topic worlds in ways that differed qualitatively from that of their non-gifted peers.

THE TYPES OF NETWORKS FORMED BY HIGH-ABILITY LEARNERS

Gifted students can think in 'larger chunks' of knowledge at a time. They retain and 'keep track of' more knowledge in their short-term memories or thinking spaces for the domain or domains in which they are gifted (Hermelin & O'Connor, 1986).

They form a personal, intuitive 'semantic theory' understanding of a topic they are learning (Schwitzgebel, 1999). This understanding is organised in a 'big-picture' hierarchical way that has more the characteristics of an expert versus a novice understanding. They infer subjective patterns and personal rules for information and organise their meaning networks in a 'big picture' way that can be described as an 'expert +' understanding (Munro, 2013a).

Gifted students can interrogate, test and validate or modify their theories. They easily generate possibilities and questions for doing this. They add this new personal understanding to their existing knowledge. This becomes their more elaborated network of meanings for the topic.

On subsequent occasions they can search what they know more rapidly and more easily recognise situations in which the information doesn't match or clashes with what they know. They can 'see' problems, inquiries, uncertainty or inconsistencies in the links between the teaching information and what they know, and see how to frame up intellectual challenges, problems or questions.

High-ability students generate this understanding in part through their selective and spontaneous use of higher level, more complex thinking strategies that differ from those used by average students (Muir-Broaddus, 1995). They more ably manage and direct their thinking activity, set learning goals, plan, rehearse, monitor or self-check, focus and persist with difficult tasks (Alexander, 1996; Alexander, Carr & Schwanenflugel, 1995). When beginning an unfamiliar task, they know better why particular strategies work, use them more efficiently and learn new strategies more easily (Annevirta & Vauras, 2001; Schwanenflugel, Stevens & Carr, 1997). They often operate as 'intuitive philosophers' and form personal theories of intelligence (Hsueh, 1997).

MULTIPLE FORMS OF GIFTED KNOWING AND UNDERSTANDING

We have noted that there are multiple forms of gifted knowing and understanding. In terms of the domain specificity of giftedness, the meaning networks link ideas within domains: for example, verbal-abstract or experiential-imagery domains and across domains.

Some students have richer, more elaborated networks of imagery knowledge while others have richer, more elaborated abstract conceptual ways of knowing a topic.

Gifted students also differ in how they think. Some gifted students learn faster: Renzulli's (2005) 'school-house giftedness' and Sternberg's (2005) 'analytical intelligence'. They are very easily programmed by the teaching information; they internalise it and form the intended understanding much faster than their peers. Their understanding comprises the network of concepts that are coded in the information.

Gifted students can do this because their more elaborated and differentiated networks allow them to process the teaching information in larger chunks and deal with more information at a time. They don't wait to be programmed in a bit-by-bit way. They infer, see the big picture, select, link and organise the main and subordinate ideas in the intended ways.

They organise and reorganise the ideas that comprise their new understanding in more complex ways. They recognise and infer the main ideas in information more rapidly than their peers. They structure and fit together the ideas in their own ways and check their interpretations against the information. Before this checking, their initial interpretations are likely to be intuitive.

Other gifted learners are more 'self-programming'. They spontaneously form a broader understanding that 'goes beyond' the teaching: Renzulli's (2005) 'creative-productive giftedness' and Sternberg's (2005) 'creative intelligence'. They infer and make links with ideas they know that are not mentioned. Con and Gus made inferences about Pythagoras that extended the teaching into their personal intuitive theories.

One way in which they do this is by making analogies between topics that seem unrelated to others; they 'see' similarities that may seem superficially different. This 'far transfer' thinking, linking topics and ideas in lateral, novel unexpected ways (Carr & Alexander, 1996) includes 'fluid analogising' (Geake, 2007). It helps them solve problems in unusual or novel ways, use imagination and fantasy and show 'intellectual playfulness'. As noted, their understanding at this time is an intuitive theory about the topic that has not yet been validated. They may not be able to justify it logically at this time but they can interrogate and investigate it.

In summary, during a teaching episode, gifted learners differ in the extent of elaboration and differentiation of the meaning networks they form. They also differ in the quality of the links, amount of knowledge they can think about at once and extent of their inferences or extensions and syntheses. The understanding of non-gifted students is usually less elaborated or extensive and more closely linked with the teaching information.

There are several other ways in which the thinking of gifted students differs from their average-learning peers. These include their attitudes and dispositions towards particular topics and to themselves as learners and thinkers, their motivation orientation, the influence of cultures to which they belong on their thinking, their concept of being a learner and their self and social identities (for example, Munro, 2013a). Limited space does not permit their analysis here.

BRAIN STUDIES TELL MORE ABOUT GIFTED LEARNING

There is converging evidence that gifted learners differ from their non-gifted peers in the neurological processes that underpin their learning. This evidence needs to be interpreted against the backdrop of disagreement about definitions and acceptable criteria of giftedness, multiple ways of being gifted and the comparatively small number of studies that examine this issue.

A repeated finding is that gifted learners show brain stimulation patterns not typically engaged by non-gifted learners ability (Geake & Hansen, 2005; Jin, Kim, Park

& Lee, 2007; O'Boyle, 2008). These stimulation patterns include the bilateral activation of the prefrontal cortex, the parietal lobes, and the anterior cingulate. Bilateral activation of the prefrontal cortex contributes to the enhanced metacognitive activity and self-management of learning and thinking noted earlier, increased spatial attention and greater working memory capacity.

The bilateral stimulation patterns permit functional contributions to thinking from both sides of the brain at any time. The enhanced interhemispheric communication (via the corpus callosum, increased grey:white matter ratio and glia:neuron ratio) assists in coordinating and integrating information between the cerebral hemispheres. Bilateral activation of the prefrontal cortex is associated with enhanced information processing and attentional functions.

The gifted learners didn't differ from their average-learning peers by engaging additional or unique network components. Instead they showed greater activation across the frontal–parietal network; their activation patterns suggested stronger interconnections than the average learner's brain. A particular network includes the prefrontal cortex, the anterior cingulate and the posterior parietal cortex. A network within the prefrontal cortex, for example, is active during fluid reasoning tasks (Geake & Hansen, 2005). The findings suggest that the gifted students have more sophisticated cognitive schemas that they use during higher level cognitive tasks.

But gifted individuals don't always show increased brain activity during cognitive task processing. Their 'more efficient brains' need less overall cortical stimulation, particularly in the prefrontal areas, to complete particular tasks (Haier & Benbow, 1995). This is the 'neural efficiency hypothesis' and it has received some empirical support. Subsequent research has showed how brain activity shifts, depending on the task and the age of the individual (Jin et al., 2007; Lee et al., 2006; O'Boyle et al., 2005). Higher ability was associated with increased parietal activity and a corresponding decrease in prefrontal activity (Klingberg, Forssberg & Westerberg, 2002). The data show a shift to more parietal activity with older subjects and with those who performed better on the task.

This trend from higher prefrontal to parietal stimulation has also be shown to depend on age for gifted learners. During fluid reasoning tasks, for example, 12- to 15-year-olds showed higher prefrontal activity (O'Boyle, 2005) while participants who were 18 years old and older showed increased parietal activity and decreased prefrontal activity. This is consistent behaviourally with the gradual automatisation of metacognitive activity with familiarity with task types.

Winner (2000) identified the following trends displayed by gifted students:

- Those gifted in mathematics, arts and music show enhanced right-brain activity when compared with average students on tasks specific to the right hemisphere, greater right-hemisphere to left-hemisphere alpha activity (Alexander, O'Boyle & Benbow, 1996) and higher right-hemisphere activation than average peers on visuo-spatial construction tasks (Jin et al., 2007).
- Those gifted in mathematics and music show enhanced bilateral, symmetrical brain organisation where the right hemisphere appears to be more involved in tasks ordinarily reserved for the left hemisphere.
- Those gifted in spatial activities are more likely to show a higher incidence of language-related disorders, including dyslexia, than non-gifted peers (Craggs, Sanchez, Kibby, Gilger & Hynd, 2006).

The domain of giftedness that has attracted greatest neuropsychological research is mathematics, studied particularly by O'Boyle and colleagues. Their studies suggest that mathematically gifted students use cortical regions not typically used by their average-learning peers. One characteristic is the enhanced development of the right cerebral hemisphere with specialised visuo-spatial processing ability and a bilateralism that involves enhanced connectivity and integrative exchange of information between the hemispheres (O'Boyle & Hellige, 1989; Singh & O'Boyle, 2004). These learners display bilateral activation of the prefrontal cortex, the parietal lobes and the anterior cingulate. The latter regions form a neural circuit that mediates spatial attention and working memory and contributes metacognitive functions (Mesulam, 2000). They influence deductive reasoning and the development of cognitive expertise (Knauff, Mulack, Kassubek, Salih & Greenlee, 2002).

The origin of the differences in neurological processes has yet to be explained. One theory that has gained in popularity over the last decade relates to the influence of *in utero* factors during the second and third trimesters, when the rate of brain development is most rapid (Mrazik & Dombrowski, 2010). This is the 'prenatal testosterone model' proposed by Geschwind and Galaburda (1987) and later taken up by investigators of gifted learning (O'Boyle, 2008).

EDUCATIONAL IMPLICATIONS

Haier and Jung (2008) noted that, while understanding the neural basis for individual differences in general ability may be the most important challenge to educators in the next decade, its relevance has attracted little empirical attention. They also noted that 'even if neuroscience results offer educators potential advances, it is not clear that the education community is ready or prepared to listen' (Haier & Jung, 2008, p. 171). The discussion in this section is made from this perspective.

For gifted learners, educational implications include protocols for identifying instances of gifted knowing and strategies for differentiating the curriculum and pedagogy. Within the limitations and restrictions noted above, the neuropsychological data suggest that both identification and teaching provision take account of these aspects:

- students' enhanced metacognitive capacity to self-manage and direct their learning activity
- students' enhanced greater working memory capacity and the ability to process and manipulate a higher information load. This leads to a capacity to engage in higher level cognitive tasks.
- students' enhanced bilateral parietal activation and the capacity to integrate understanding from multiple codes. This includes pedagogy that scaffolds spatial and visual imagery.
- students' capacity to engage in far transfer and fluid analogy and to generate intuitive theories about topics they are learning.

Identification procedures can assess each of the aspects. Pedagogic provision can take account of them. Munro (2013b) explores these links explicitly.

An example of the potential interaction between cognitive-affective and neuropsychological studies of gifted understanding relates to the description of gifted understanding from the perspective of the 'expert knower' model. Cognitive analysis of the trend from a novice to an expert understanding of a topic identifies the critical role of metacognition (Bransford, Sherwood, Vye & Rieser, 1986). Research of gifted learning identifies this as a distinguishing feature. The review of the neuropsychological research shows the enhanced activity of the prefrontal cortex. What this approach also shows are the likely links made by the prefrontal with the parietal cortex, thus facilitating the likelihood of unusual or 'creative' outcomes. The bilateral activation matches the enhanced working memory capacity needed to achieve the 'expert+' understanding characteristic of gifted learners.

Linking the cognitive-affective and neuropsychological approaches has much to offer. It may, for example, allow gifted understanding to be described in terms of its 'quality', complexity and extent of differentiation. This could assist in resolving the current disagreements about what constitutes criteria for giftedness and the protocols used to identify it.

IN SUMMARY

Gifted students differ from their non-gifted peers' regular classroom learning-teaching interactions in their capacity to generate intuitive theories about the topics they learn. Their networks of meanings contain both links that are programmed by the teaching and links that are, at one time, more personal and intuitive. Studies of the neuropsychological processing of these students are consistent with this. Synthesised with psycho-educational research, they provide the opportunity for resolving current issues in our understanding of giftedness and efficacious educational provision.

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LEARNING, REMEMBERING AND FORGETTING IN THE MAMMALIAN BRAIN

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Professor Pankaj Sah is a neuroscientist who is currently Deputy Director (Research) at the Queensland Brain Institute. After training in medicine, he did his PhD at the Australian National University. Following postdoctoral studies at the University of California, San Francisco, and the University of Queensland, he established his own laboratory in the Department of Physiology at the University of Newcastle in 1994. He then moved as group leader to the John Curtin School of Medical Research at the Australian National University and was recruited as a founding member of the Queensland Brain Institute in 2003. His interests are in understanding the mechanisms that underlie learning and memory formation in the mammalian brain. His laboratory is known for studying the amygdala using a combination of molecular tools, electrophysiology, anatomical reconstruction and calcium imaging. He has published more than 90 papers in international peer-reviewed journals and has been on the editorial board of several international journals including the *Journal of Neuroscience* and the *Journal of Neurophysiology*.

ABSTRACT

Education in its most general sense is a form of learning in which knowledge is imparted from one source to another. The delivery of education and the testing of its impact has been an ongoing human endeavour for many years and ideas on how to manage education have largely resulted from theories of education. The acquisition, storage and retrieval of learned behaviours result from brain activity. Using a variety of experimental approaches, studies in neuroscience have been considering the issue of the physiological mechanisms that mediate learning and memory formation and its retrieval. These studies are not only providing insight into the basic physiological and molecular mechanisms that underpin learning but also some surprising findings on the impact of the environment and presentation state on learning and recall of learned events. In this session, I will discuss current ideas of learning and memory formation in the mammalian brain and possible implications for education practice.

Learning is a lifelong process by which we acquire new facts and skills, or modify existing ones as a result of experience. It provides the knowledge and skills necessary to respond successfully to the challenges that we face throughout our life. Education, in a general sense, describes the delivery of learning in which knowledge is imparted from one source to another. The ability to learn is present in all living organisms but particularly in humans and primates. Learning requires first the understanding of novel situations and the formation of a response to these situations that leads to particular, desired outcomes. Secondly, the ability to respond appropriately in the future requires the storage of information that underpins this understanding, and its effective retrieval.

Thinking about the nature of memories, how they are formed and how we learn goes back to the time of the ancient Greeks. Aristotle placed the seat of thinking in the heart but had surprisingly modern ideas about learning: for example, he thought that learning resulted from an association of ideas. Learning and memory have until relatively recently been the exclusive province of philosophers, in large part due to the influence of René Descartes (1596–1650), a pivotal figure who separated the mind from the body. He described the body, including the brain and the entire nervous system, as one type of object (*res extensa*), with length and breadth that could be objectively measured and studied. In contrast, the mind was a fundamentally different substance (*res cogitans*), responsible for thoughts, desires and volition but with no physical structure and indivisible. As such, the mind was not amenable to experimental analysis. Descartes' ideas were a dominant influence on theories of the mind and effectively put the study of learning and memory out of the scientific arena.

It has long been known that all animals have a brain, and that the capacity to learn and remember is an integral part of their behaviour. But it had been taken for granted that humans were fundamentally different from animals. By the turn of the 20th century, it was well established that activity within the central nervous system is the basis for higher cognitive function. The experimental study of learning and memory began in the late 19th and early 20th century, and owed a great deal to the writings of Charles Darwin, who appreciated that all behaviour must have a biological basis. The natural extension of this idea was that clues to human behaviour could be found by studying animals. Indeed, not long after the publication of the *On the origin of species* (1859), the first physiological studies of learning were conducted by the Russian psychologist Ivan Pavlov (1849–1936) who studied classical conditioning in dogs. Modern ideas about the biological underpinnings of learning and memory begin with the Spanish neuro-anatomist Ramón Y Cajal (1852–1934). Cajal discovered that the nervous system was composed of individual cells. These cells, called neurons, were separate entities and communicated with each other at specialised junctions, a finding for which he shared the Nobel Prize in Physiology or Medicine in 1906. In his Croonian Lecture, delivered to the Royal Society in 1894, Cajal described his findings that nerve cells form connections with each other, and suggested that learning may be due to changes in the strength or pattern of connections between neurons. This idea, that a modification of the connections between neurons is the basis for learning, was formalised by the Canadian psychologist Donald Hebb in his book *The organisation of behaviour* (1949). Hebb proposed that during learning, if a particular connection between neurons is repeatedly used such that activity in one cell drives activity in the other, the strength of the connection between these cells is strengthened. Evidence for an activity-driven change in synaptic strength was first demonstrated at synapses in the hippocampus in 1973 and called long-term potentiation (LTP – Bliss & Lømo, 1973). It was well known that the hippocampus played a key role in memory formation (Milner, Squire & Kandel, 1998), and the finding of LTP in the hippocampus set the scene for the biological study of memory formation and LTP, a form of synaptic plasticity that remains the main cellular mechanism for learning and memory formation (Bliss & Collingridge, 1993).

Memory is a word that is used in a number of different contexts. For scientists, memory typically refers to the ability to encode and store information. Memory can also refer to something that is stored in the brain or the experience of remembering something. As a biologist, in this review, I will use memory as the first of these and discuss our current understanding of memory encoding. Memories are also separated into two categories: procedural or implicit memory; and declarative or explicit memory. Implicit memory relates to those that involve changes in behavioural outcomes, such as learning to ride a bicycle or playing the piano. In contrast, explicit memories are those that relate to memories of events and episodes, and are the type we are most commonly aware of. Importantly, emerging literature is showing that both types of memory formation engage similar biological mechanisms, and have very similar time courses.

Memory formation is thought to result from changes in the strength of connections between neurons involved in particular circuits, and is known as synaptic plasticity. Over the last 20 years, studies in animals have led to very specific cellular and molecular models of learning and memory formation (Kandel & Pittenger, 1999). Many of these findings come from analysis of simple forms of learning such as spatial learning and Pavlovian conditioning. These studies have shown that learning and memory formation result from two forms of plasticity: synaptic plasticity and neurogenesis. Synaptic plasticity refers to changes in synaptic strength of connections in existing networks of neurons, by the process of LTP, and is initiated by the coincident activity of cells that are engaged in networks that process related ideas. Neurogenesis, by contrast, refers to the generation of new neurons and their integration into the existing neural circuitry (Ming & Song, 2011). How particular neurons are generated and when this process is initiated is less well understood but engaging either LTP or neurogenesis has effects on neural activity, and leads to functional outcomes in cognitive state and behaviour.

All learning results from the observation, manipulation and storage of information, and the long-term impact of any learning clearly depends on the efficacy and accuracy of recall. Different types of memory clearly engage different neural circuits (Squire, 1987), and studies over the last 20 years have established that memory formation proceeds in three phases: acquisition, storage and retrieval (McGaugh, 2002). The first step, acquisition of memory, is immediate and is thought to result from LTP at particular synapses. This initial memory then undergoes a process of consolidation and storage. Consolidation refers to the fact that memories are initially formed in a somewhat labile form, after which processes are initiated during which they are transformed to a different state and become long-term memories. Initial memory formation is initiated by local biochemical changes at synapses that are engaged during a particular learning experience. In particular, it is clear that these cascades require the activity of receptors called N-methyl-D-aspartate (NMDA) receptors that are activated by the neurotransmitter glutamate, and a rise in cytosolic calcium at the synapse (Collingridge & Bliss, 1987). This rise in calcium activates second messenger systems that result in strengthening of that synapse (LTP). However, this form of LTP is relatively brief, lasting from one to three hours. Activation of NMDA receptors also initiates a different set of signalling cascades that lead to changes in gene expression in the neurons involved, leading to long-lasting changes of synaptic activity. In areas of the brain such as the hippocampus, activation of NMDA receptors also initiates neurogenesis in which new cells mature and integrate into the existing neural circuits, and this activity is required during memory consolidation. Both animal and human studies have shown that memory acquisition and consolidation is highly dependent on the learner's mental and emotional state, the method of information presentation, how performance is reinforced and the environment in which the person learns. Thus, both memory formation and consolidation also respond to modulatory influences.

Memory recall is the retrieval of information that has been stored. Two types of recall are generally recognised: free and cued recall. Free recall refers to the situation where events are retrieved at random, whereas, in cued recall, particular events are retrieved in a particular order as a result of an external cue. As described above, memory storage is thought to require activity of particular neural circuits and changes in the strength of connections within these circuits. For some forms of memory, in particular simple forms of learning, it is now clear that during memory recall, presentation of the cue activates the same neurons (the 'engram') that were engaged during acquisition. Indeed, stored memories of a particular event can be revived by selective activation of neurons that were engaged during the acquisition phase.

Consolidation of memory is thought to result in a long-lasting, stable memory trace. But it has been known for many years that recall of stored memories can destabilise the stored memory and it undergoes a second round of reconsolidation. In recent years, this proposal has grained much traction in studies again using Pavlovian conditioning in which the underlying mechanisms have been examined. These studies suggest that after recall of a stored memory, biochemical changes in neurons that represent the stored memory are destabilised, and a second round of genetic changes are required for permanent storage. The reasons for this reconsolidation are not clear but it has been suggested that this mechanism provides the opportunity to update stored memories based on new information. These results also suggest that procedures may be able to be implemented that enhance the second round of consolidation, thus leading to better long-term storage of information. These results provide an explanation for how rehearsal (practice) improves memory.

Forgetting? Memory formation is thought to result from plasticity within the nervous system, and retrieval of these memories results from reactivation of the 'engram' that is laid down during memory consolidation. The question arises: is forgetting an erasure of this engram?

We all have had the experience when facts that appear to have been forgotten at some time can be remembered when circumstances change. Studies in animal models have also provided a possible explanation for these changes. In Pavlovian fear conditioning, a normally innocuous stimulus (the conditioned stimulus), such as a tone or light, is contingently paired with a noxious one (typically an electric shock, the unconditioned stimulus) so that the conditioned stimulus now predicts the onset of an aversive stimulus. After a number of conditional stimulus–unconditioned stimulus pairings, subjects come to respond to the conditioned stimulus with behavioural, autonomic and endocrine responses that are characteristic of defensive responses to a fearful stimulus (the conditioned response). This is a form of Pavlovian learning, and involves the storage of 'emotional' memories that are rapidly acquired and long-lasting (Maren, 2001). In this process subjects learn that encountering the conditional stimulus predicts an aversive outcome, is therefore dangerous and respond appropriately. But after the formation of this memory, subsequent repetitive presentations of the conditional stimulus, not paired with the unconditioned stimulus, break the previous association, and leads to a gradual reduction of the conditioned response through a process known as extinction. Thus, a memory that a particular conditioned stimulus was dangerous and predicted an aversive outcome was formed and consolidated. After extinction, it may appear that this memory has been forgotten, as the conditioned stimulus no longer evokes the original learnt response. But experiments have shown that, rather than being forgotten, recall of this original memory has only been inhibited. New learning has taken place that interferes with recall of the old association. Under different circumstances, the original memory can return. These experiments have focused on one form of simple learning, and show that memories that appear to be forgotten are in fact still intact. Similar mechanisms have been shown to operate for a variety of different memories suggesting that similar mechanisms may also be engaged for more complex memories.

In this brief review, I have described some of the cellular mechanisms that underpin memory formation, storage and recall. These findings come from experimental studies in animals coupled with molecular and genetic studies using simple learning paradigms where learning can be simply assessed. But in our daily lives and in education, we learn much more complex relationships and form complex memories. How these memories may be formed and whether they fit into the physiological structure I have described will require some understanding of how particular episodes are encoded at the neural level. It is clearly going to require a multifaceted approach in which experimental neuroscience collaborates with educators and psychologists. The Centre for the Science of Learning is a starting point to bring together these different disciplines. Similar activities are also supported overseas and present a bright future for this endeavour.

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FROM EXPERIMENTAL PSYCHOLOGY TO A SCIENCE OF LEARNING

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Professor Ottmar Lipp, FASSA, FAPS, is an experimental psychologist who received his training at the University of Giessen, Germany. He joined the University of Queensland as a post-doctoral research fellow in 1991 and has held faculty appointments since 1994. He was awarded an Australian Professorial Fellowship from the Australian Research Council in 2007 and a University of Queensland Senior Research Fellowship in 2012.

His research is concerned with human emotional learning and the interrelation between human emotion and attention. He has published more than 100 papers in international peer-reviewed journals and has obtained more than $1.2 million in research funding. He is currently the editor-in-chief of the journal *Biological Psychology*.

His teaching covers the areas of associative learning, emotion and psychophysiology. His efforts in undergraduate teaching and postgraduate supervision were recognised with teaching awards at the university and national level. In 2004–05, he led a discipline-based project to review the teaching of psychology in Australia. Since 2009, he has acted as one of the co-directors of the University of Queensland's Science of Learning initiative.

SACHA DEVELLE

Dr Sacha DeVelle has an extensive teaching and research background in educational assessment and psycholinguistics gained from working in Australia, the UK, Latin America and East Africa.

Her undergraduate degree in psychology and Spanish at the University of Queensland was the impetus for further postgraduate study into language processing. It was there that she coordinated the psycholinguistics laboratory within the linguistics program, and lectured on a range of linguistics, Spanish and ESL subjects for a number of years.

In 2007 she joined the Research and Validation Unit, University of Cambridge ESOL, where she was responsible for the IELTS research agenda and language-testing projects across the organisation. Since then she has managed projects in Uruguay, Brazil, Uganda, Ethiopia and Rwanda, and has specific expertise in advising on education programs within developing contexts.

Dr DeVelle has a particular interest in how the brain processes language at the semantics–pragmatics interface. She has presented and published extensively on this topic. Her more recent research has extended this work to deaf communities in Uganda, East Africa.

ABSTRACT

Human learning has been one of the core topics of psychology since its inception as an independent discipline in the late 19th century. Nevertheless, if one were to tally the contributions that experimental psychology has made to enhance learning in practice, only a rather brief list would emerge. This rather disappointing picture is slowly changing. By drawing on recent developments within experimental psychology and cognitive neuroscience, it is possible to highlight a number of promising approaches to the development of a translational educational science that connects basic psychological research and educational practice. Phenomena like the testing effect or the practice of interleaved training hold considerable promise to support enhanced learning across various settings and content areas, through building on strong empirical evidence. But the challenge remains to bridge the gap between the research laboratory on the one hand and the classroom on the other. The concept of the experimental classroom that affords the level of control required for the systematic study of human learning as well as the realism of a 'live' teaching and learning setting is proposed as an answer to this challenge.

INTRODUCTION

Recent discoveries in cognitive neuroscience, experimental psychology and education (Goswami, 2006; Howard-Jones, 2011; Roediger, 2013) have raised new questions about how learning takes place, and further emphasised the need for interdisciplinary collaboration, for a new 'science of learning'. But, as in most cross-disciplinary settings, such a dialogue is not easy and the science of learning is no exception. The Science of Learning Research Centre (SLRC) was recently established to provide a base for the cross-disciplinary study of human learning, and brings together researchers in education, neuroscience and cognitive psychology from three lead institutions – the University of Queensland, the University of Melbourne and the Australian Council for Educational Research (ACER) – plus a number of partner institutions (Macquarie University, the University of New England, Deakin University, Charles Darwin University and Flinders University). Two experimental classrooms, one at the University of Queensland and one at the University of Melbourne, will be at the core of the centre. Importantly, any successful bridge between the laboratory and the classroom will depend on, firstly, a common language and, secondly, a joint ownership of the research that is beneficial to such interdisciplinary collaboration (Howard-Jones, 2011). This session outlines how research from the Science of Learning Research Centre can contribute towards a translational educational science, allowing educators to select evidence-based learning methods (Roediger, 2013). The discussion starts with a brief description of cognitive neuroscience and experimental psychology to highlight their similarities and differences. We then turn to two results from experimental psychology research that hold considerable promise for the classroom. We finish with more detail about the Science of Learning Research Centre and the experimental classroom environment.

INTERDISCIPLINARY RESEARCH: A SCIENCE OF LEARNING

There is a plethora of experimental psychological research on human learning, considering issues such as working memory, motivation, attention and emotion, language development, learning difficulties or child development. Much of those findings have implications for all levels of education, from the learner and teacher to the policy adviser. Experimental psychologists traditionally use behavioural measures such as response times or response accuracy. In recent years measurement of brain function has complemented these behavioural measures. (These methods of measurement include electroencephalography – EEG – and event related potentials – ERPs – as well as functional magnetic resonance imaging – fMRI. Such methods are complementary in the aspects of brain activity they reflect – electrical versus brain blood flow – and the information they provide – high temporal resolution versus high spatial resolution.) Cognitive neuroscience aims to explore the neural bases of cognitive and behavioural phenomena using these brain-imaging methods. Much has been achieved in this field to answer the 'where' question – which are the brain areas that contribute to the behaviour in question? Of more interest is the 'how' question: how does the brain solve a particular task placed in front of it? The field overlaps with experimental psychology to the extent that it asks very similar questions, and many cognitive neuroscientists have a background in experimental psychology. Let us now look at two findings from experimental psychology that hold considerable implications for learning in the classroom. These are the stability bias in memory and the testing effect.

STABILITY BIAS IN MEMORY

Students are expected to take some responsibility for their own learning. But to carry this out successfully they must possess the metacognitive skills that support the learning process. Predicting how further practice can strengthen memory is a crucial skill, particularly when making decisions about the content and extent of future study. Kornell and Bjork (2009) carried out a series of memory experiments to assess students' ability to make this judgement. Having studied a set of easy and difficult items once, students were asked to predict their level of performance immediately or after 1, 2 or 3 additional study sessions. Although the students held the metacognitive belief that studying enhances learning and thus performance, they underestimated the performance gain due to further study by up to 33 per cent. Thus, having completed additional study sessions, students performed significantly better than they had predicted after the initial study session. This finding is complemented by the observation that students systematically underestimate the extent to which they will forget materials that they have studied previously. Koriat, Bjork, Sheffer and Bar (2004) asked students to learn a list of easy and hard items and informed them that they would be tested either immediately, a day or a week later. Students were very good at predicting performance in the immediate test. They were woeful in anticipating the detrimental effect that the passage of time would have on their performance. Taken together, these results provide evidence for a stability bias in the evaluation of memory performance (Kornell & Bjork, 2009). Students underestimate the benefits of additional study and overestimate the stability of memories that they have acquired. These findings are based on standard memory paradigms as used in experimental psychology research. There is no research that examines whether the stability bias scales up from the simple experimental paradigms employed in the laboratory to the more complex classroom environment. The question of particular relevance to researchers at the Science of Learning Research Centre is how to overcome this bias so that students become better predictors of their own performance, either as a function of additional practice or as a function of forgetting.

TESTING EFFECT

There is a vast literature showing that practice testing improves learning. This work has highlighted the importance of dosage (more is better) and time interval between tests (longer is better) among other factors (Logan & Balota, 2008). More recently, Roediger and Butler (2011) reviewed literature on the testing effect, which suggests that having a test on particular material enhances performance more than rereading or having no re-exposure. Students who received repeated testing were shown to outperform students who had only one test before a delayed final examination one week after study. In contrast, the number of study trials completed in the two testing conditions did not seem to affect performance at test. The effect of testing can be enhanced if feedback is provided as to accuracy. Interestingly, delayed feedback seems to be more beneficial than immediate feedback. Moreover, it is thought that repeated testing enhances transfer and the flexible use of acquired information. The testing effect is thought to reflect on the benefits of repeated retrieval practice, and the notion that effortful retrieval of a memory and its reconsolidation will strengthen retention. Less is known about the role of other processes such as self-generated feedback or the correction of memory biases (see above) in mediating the testing effect. The testing effect has clear implications for student learning but it is necessary to broaden the paradigms and contents currently used in its investigation so they become more relevant for educational practice.

We have reviewed as examples two findings from basic experimental psychology research that have clear implications for the enhancement of student learning (for further elaborations and examples, see Dunlosky, Rawson, Marsh, Mitchell & Willingham, 2013). The next step is to involve settings and materials that resemble those used in the classroom, while maintaining the strengths of the experimental approach – control and reproducibility. This is where we see the role of the experimental classrooms that form the core of the Science of Learning Research Centre.

THE SCIENCE OF LEARNING RESEARCH CENTRE

The research centre is funded under the Australian Research Council's Special Research Initiatives scheme. It brings together researchers from the areas of neuroscience, cognitive psychology and education to perform research on human learning. Bringing together such a diverse group of researchers, who differ widely in theoretical background and methodology, is challenging. Moreover, the centre will engage with stakeholders in government and with educational practitioners. Engaging with educational practitioners is of vital importance for two reasons. First, it will help the centre to perform research that is of practical relevance. We have no doubt as to the importance of basic research, as illustrated by the examples cited above that emerged out of basic research. However, if the centre is to achieve its objectives it must align the research with the requirements of educational practice. Second, early engagement with educational practitioners can only help facilitate the implementation of research outcomes. The platforms that will permit us to realise this ambitious collaboration (between researchers from very different backgrounds and between researchers and practitioners) are the experimental classrooms: one at the University of Queensland and one at the University of Melbourne. The classrooms will serve as conduits that connect laboratory-based research with educational practice in a two-way street of information exchange (see Figure 1).

The two experimental classrooms will be set up to complement each other and will leverage existing expertise in cognitive neuroscience (Queensland) and observational classroom research (Melbourne). The Queensland classroom will permit the monitoring of electrocortical activity, eye movements and peripheral physiology while small groups of learners engage in a variety of different tasks. This will enable the online assessment of cognitive processes as well as of performance measures. It will provide insights into the manner in which, for instance, the attentional engagement with study material changes as learners become more proficient at a given task or the manner in which different types of feedback enhance learning. The Melbourne classroom will permit the audiovisual monitoring of teacher–student and student–student interactions as they occur in a realistic classroom setting. This will enable the fine-grained analysis of both social

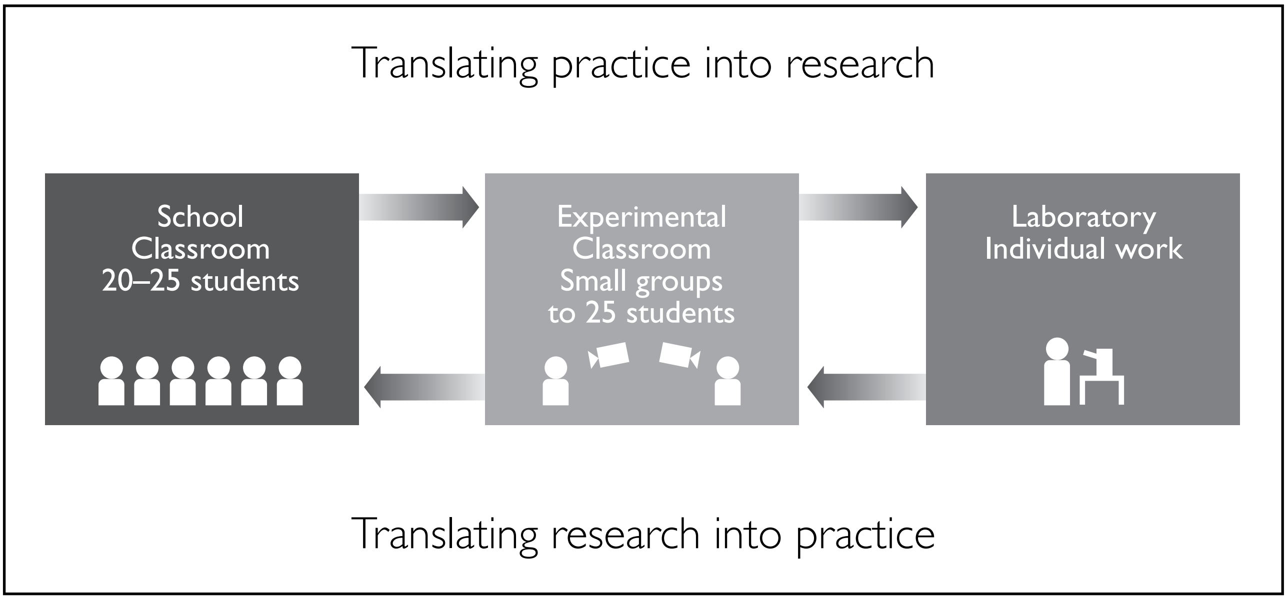

Figure 1 The experimental classroom as the connection between classroom and laboratory

interactions that characterise a learning situation and those that influence the learning process. It will provide insights, for instance, into the manner of how teachers and students respond during what they respectively perceive as the most critical moments of a particular lesson. It will also provide the opportunity for immediate feedback to teachers and students for a more in-depth gathering of information about the role of social interactions in class.

CONCLUSIONS

Education is about enhancing learning – experimental psychology and cognitive neuroscience investigate 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' (Royal Society, 2011). The Science of Learning Research Centre is designed to provide the platform to make this vision a reality. It will provide opportunities for research that will enhance our understanding of human learning and the factors that promote it and that will provide the base for a translational educational science.

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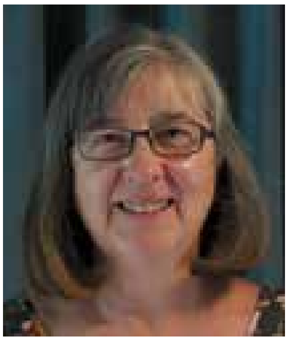
BEING THE BEST LEARNER YOU CAN BE: TRANSLATING RESEARCH INTO EDUCATIONAL PRACTICE



DONNA NITSCHKE
Coordinator Neuroscience in the Classroom

Ms Donna Nitschke is currently the Coordinator Neuroscience in the Classroom across a cluster of four Adelaide primary schools.

She has worked in the field of education for most of her adult life and been employed as a teacher at all year levels from preschool to year 12. She has lectured at university as well as TAFE and worked for a number of specialist educational organisations including Autism SA, the Down Syndrome Society and Novita. She was also a Senior Project Officer for the Ministerial Advisory Committee: Students with Disabilities. In 2006, Donna completed the Graduate Certificate in Neuroscience (Learning), a joint venture between the three universities in Adelaide. Since 2009, she has been developing a neuroscience-based program for primary schools entitled Being the Best Learner You Can Be.

ABSTRACT

Being the Best Learner You Can Be is a classroom-based program developed for students from preschool to Year 7. Based on current neuroscience research, this program seeks to improve student learning outcomes by providing students with the underpinning tools that allow them to engage with learning, monitor their own progress and, thus, successfully navigate the school environment. In this sense, it differs from other 'brain-based' educational packages by providing a range of cognitive, emotional and conceptual 'tools for improvement' directly to students thereby placing the onus for 'training their brains' on the students as well as on their teachers. In addition, rather than singling out a unit of study on attention or emotional development, this program synthesises all of the factors that contribute to learning (including attending capacities and emotional development) within the same package.

> *Education is about enhancing learning, and neuroscience is about understanding the mental processes involved in learning. (Frith, 2011, p. v)*

In the last 20 years, neuroscience research (generally defined as the 'study of the brain and nervous system, including molecular neuroscience, cellular neuroscience, cognitive neuroscience, psychophysics, computational modelling and diseases of the nervous system' (MedicineNet, 2013) has enormously expanded our understanding of human brain function and development. We now understand that each person's brain 'wires' or develops in very individual ways based both on unique genetics and also on a vast range of personal experiences (Blakemore & Frith, 2005; Giedd et al., 1999). Foundational brain development takes place during two significant growth periods in the early years and during adolescence. But the learning that takes place in between these two periods is also important, since all brains respond to new learning and experience with structural change to neural networks. This phenomenon is commonly referred to as 'neuroplasticity' (Shaw & McEachern, 2001) and is validation for a model of learning proposed originally by Donald Hebb more than 50 years ago.

The concept of neuroplasticity is both good news and bad, in that individuals are born with a blueprint for how their brains could and should develop. But they require the necessary inputs to stimulate the brain to develop according to that template. When appropriate input is not provided, an individual's brain will not realise its potential or, worse, a variety of emotional, behavioural, perceptual and learning difficulties may occur.

DEVELOPING A NEW FIELD OF 'NEUROEDUCATION'

Throughout the 2000s, there has been a growing call for an interdisciplinary partnership between neuroscience researchers and classroom educators (Baker, Salinas & Eslinger, 2012; Blakemore & Frith, 2005; Frith, 2011; Geake, 2009; Goswami, 2006; Howard-Jones, 2008a, 2008b, 2009; LIFE Centre, n.d.; Meltzer, 2007; OECD, 2002, 2007; Pickering & Howard-Jones, 2007; Reed & Brescia, 2011). As the initial quote above indicates, the core business of both education and neuroscience is learning. But, while neuroscience is unpacking various aspects of human brain function and learning at a rapid rate, the practical application of this information remains problematic for school-based educators for a number of reasons:

- the overwhelming speed of conceptual change occurring in neuroscience, including the development of new disciplines such as 'affective neuroscience' (Carew & Magsamen, 2010; Frith, 2011; Goswami, 2006; Howard-Jones, 2007)
- the technical nature of reported findings coupled with professional discipline barriers arising from perceptual paradigms and discipline-specific language (jargon) that create a lack of access to useful information for educators (Carew & Magsamen, 2010; Dekker, Lee, Howard-Jones & Jolles, 2012; Frith, 2011; Samuels, 2009)
- the proliferation and confusion caused by neuro-myths based on an over-extrapolation of research findings (Carew & Magsamen, 2010; Dekker et al., 2012; Frith, 2011; Goswami, 2006; Howard-Jones, 2007, 2008c)
- a burgeoning array of commercial 'brain-based education' packages that are often spruiked without enough strong research evidence to underpin them (Dekker et al., 2012; Frith, 2011; Goswami, 2006; Howard-Jones, 2007, 2008c; Samuels, 2009)
- lack of appropriate training for teachers to allow them to cope with the points above (Carew & Magsamen, 2010; Dekker et al., 2012; Frith, 2011; Howard-Jones, 2008b, 2008c, 2009; Samuels, 2009)
- curriculum, attitudinal, financial and time pressures on classroom teachers.

In both the USA and the UK, there are organised groups of neuroscientists seeking to assist educators to access quality research in relation to policy and practice (Baker et al., 2012; Dekker et al., 2012; Frith, 2011; Goswami, 2006; Howard-Jones, 2007, 2008a, 2008b; LIFE Centre, n.d.; OECD, 2002, 2007). In comparison, the Australian dialogue between researchers and educators is in its infancy.

Although neuroscience research is hugely varied and ranges from the study of genetic matter within individual genes right through to more conceptual research involving the study of an 'ethical' brain, there is general consensus about the important key aspects of neuroscience research for educators. Based on the growing understanding of our brain plasticity, key concepts relevant for educators centre around the following:

- general brain development including neural pathways, neural networks, neural systems and the interactions between neural systems

- metacognition, including relationships (both knowledge-based and interpersonal)
- memory systems
- attention systems
- emotional systems
- theories of learning.

There are different motivational aims in how researchers and educators conceptually weave research information with school-based teaching and learning processes.

CONCEPTUALISING NEUROSCIENCE AND EDUCATION

In reviewing the literature this author has concluded that the synthesis of neuroscience research and education can be viewed from the following three foci:

- increased knowledge (for example, scientific information usually absorbed into the science–health curriculum)
- increased educational or therapeutic direction through enhanced diagnostic and supportive capacity for students with additional needs (for example, dyslexia or autism)
- improved practice
  - guidelines for educators in framing and presenting the curriculum
  - a basis for improving individual learning skills across the entire student population.

The literature can be further divided within this third point to include research from the outside – academics in various fields looking to test and apply findings within the education paradigm – and from the inside – educators looking at the growing body of research to discover what may be of practical use in the formation of policy, curriculum and school environments.

THE BEING THE BEST LEARNER YOU CAN BE PROGRAM

The Being the Best Learner You Can Be program falls firmly within the latter category of improved practice taken from an insider perspective (that is, what adds value to and works within a schooling paradigm). Specifically, this program is designed to help students, in the first instance, to build an awareness and understanding of the various executive functions that underpin learning and, in the second instance, to learn to test, practise, review and take responsibility for their personal skills development. The program also aims to improve framing and delivery of curriculum by teachers.

Using a games-based format underpinned by explicit teaching regarding brain development, the program focuses on helping students to improve attention, memory, emotional literacy and higher order thinking skills so that academic and social outcomes are maximised. Aspects of general health such as sleep, diet and exercise are included in the program as these directly contribute to brain function and, therefore, learning. The overriding emphasis of the program is learning focused and defines learning as that which the student does or does not do in response to input. This contrasts with a teaching or curriculum focus, being that which a teacher delivers to a student.

In constructing the program, it was important to determine the most relevant research areas for this purpose. When including concepts and activities in the program, choice was guided by the following two questions:

- has the research been well constructed and verified?
- does this information or approach serve to develop or improve executive function skills and, if so, how?

To define what constitutes well-constructed and verified research, the author has drawn on the approach of the Johns Hopkins University's Center for Research and Reform in Education and the University of York's Institute for Effective Education (see their online resource, Best Evidence Encyclopedia at http://www.bestevidence.org).

The definition of executive function was more problematic. While executive functions are frequently referred to in educational literature (especially in relation to students with disabilities) and widely researched in various disciplines such as neuroscience and psychology, the exact definition of what constitutes 'executive functions' is still unclear. As reported by Zelazo and Müller (2011, p. 574), 'Executive function (EF) is an ill-defined but important construct that refers generally to the psychological processes involved in the conscious control of thought and action.'

Given that the term 'executive function' is used in reference to an array of skills and abilities, it was decided to largely adopt the definition and approach put forward by Peg Dawson (Dawson & Guare, 2004). This decision was made based on both face validity and general transferability into a primary school setting. Hence, the suite of executive functions that form the Be the Best Learner You Can Be program's structural basis are the set of cognitive abilities that control and regulate other abilities and behaviours and that are necessary for goal-directed behaviour. As framed by Dawson, this includes all skills that allow individuals to anticipate outcomes, adapt to changing situations, form concepts and think abstractly. Specifically, the program has targeted and expanded Dawson's set of executive function skills to encompass the following:

- plan (ability to create a road map to reach a goal)
  - organise
  - time manage
- working memory (both verbal and non-verbal)
- metacognition (self-knowledge and higher order thinking)
- response inhibition
  - delay gratification ('with style')
  - stop unsuccessful behaviours
  - manage distractions or interruptions
- self-regulation for affect (ability to manage emotions)
- task initiation
- flexibility (revise, problem solve, error correction)
- goal-directed persistence (adapted from Dawson & Guare, 2004).

Figure 1 Poster created for the Be the Best Learner You Can Be program by the author

In the classroom, emphasis is placed on developing executive function skills through a process of self-discovery (see Figure 1). The suite of games used during lessons has been developed to help students recognise their individual strengths and weaknesses. After each game, students are directed to strategies they can use to make personal improvements.

CONCLUSION

The rapidly developing area of neuroeducation holds much promise for improving both teaching and learning in our schools. In Australia, this is largely uncharted territory. The Be the Best Learner You Can Be program represents one approach for translating research into viable practice.

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DO BOYS AND GIRLS READ DIFFERENTLY ONLINE? EVIDENCE FROM PISA 2009 DIGITAL READING ASSESSMENT

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He has had major involvement in a wide range of other projects assessing the reading and writing proficiency of school students and adults in many countries, including New Zealand, the UK and the United Arab Emirates. Before joining ACER, Tom held research and teaching posts at the University of Melbourne and Hong Kong Polytechnic University. In earlier years he played a major role in the development of a range of language tests and classroom-based assessment procedures used in Australia and South-East Asia.

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ACER

Dara Ramalingam is a Senior Research Fellow at the Australian Council for Educational Research. She is part of a test development team that specialises in constructing, describing and validating developmental continua, particularly in the area of language and literacy. She is currently the manager of instrument development for the computer-based assessment of problem solving for the OECD's Programme for International Assessment (PISA) and co–project director of ACER's International Schools' Assessment (ISA). She played a leading role in test development for the PISA 2009 Reading Assessments (both digital and paper-based) and the OECD Programme for International Assessment of Adult Competencies computer-based assessment of literacy. In addition to her international work, Dara has extensive test development experience for national and state-based assessment work in Australia.

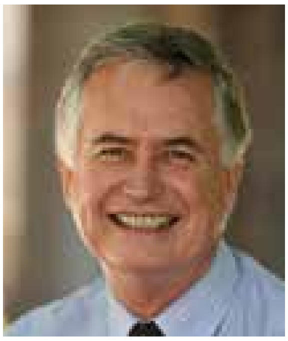
JULIETTE MENDELOVITS

ACER

ABSTRACT

According to the results of PISA 2009, while girls are more proficient readers than boys in both print and digital media, it appears that the gap in performance is narrower in the digital medium. It has been suggested that the narrowing of the gender reading gap might be attributed to relatively strong navigational skill on the part of boys. This presentation will explore the evidence for this suggestion, and will also look at other possible reasons for boys' relative success in the PISA digital reading assessment, including the types of texts represented in the assessment and the proportions of different item formats.

CHALLENGES AND OPPORTUNITIES FOR NEUROSCIENCE: HOW TO EXPLAIN THE CONNECTION BETWEEN SOCIOCULTURAL PRACTICES AND COGNITION?



DAVID CLARKE
University of Melbourne

Professor David Clarke is the Director of the International Centre for Classroom Research (ICCR) at the University of Melbourne. Over the last 20 years, his research activity has centred on capturing the complexity of classroom practice through a program of international video-based classroom research. The ICCR provides the focus for collaborative activities among researchers from more than 20 countries. Professor Clarke has worked with school systems and teachers throughout Australia and in the USA, Canada, Sweden, Germany, the Netherlands, Italy, Singapore, China, Japan, Malaysia and the Federated States of Micronesia. Other significant research by Professor Clarke has dealt with teacher professional learning, metacognition, problem-based learning, and assessment (particularly the use of open-ended tasks for assessment and instruction in mathematics). Current research activities involve multi-theoretic research designs, cross-cultural analyses, discourse in and about classrooms internationally, curricular alignment and the challenge of research synthesis in education. Professor Clarke has written books on assessment and on classroom research and has published his research work in more than 150 book chapters, journal articles and conference proceedings papers.

HILARY HOLLINGSWORTH
ACER

Dr Hilary Hollingsworth's main areas of interest are teacher professional learning and the assessment of student learning, and her current work foci include teacher evaluation and assessment, classroom observation frameworks, the use of video for teacher professional learning and the assessment of student learning. Dr Hollingsworth's interest in these areas was sparked by her doctoral studies and her extensive international experience working as the Australian representative on the TIMSS Video Study projects and as a director of teacher learning for LessonLab in Los Angeles, California. Dr Hollingsworth's experience related to teacher professional learning and the assessment of student learning extends across system and school levels. She has developed graduate programs and professional learning modules for teachers, and delivered numerous keynote addresses at education conferences. She regularly provides consultancy services to schools in different sectors and geographical regions, and completes projects for organisations including the Australian Association of Mathematics Teachers, the Australian Institute for Teaching and School Leadership, and Education Services Australia. Dr Hollingsworth has recently worked as a senior lecturer in the Melbourne Graduate School of Education at the University of Melbourne and is conducting research there related to classroom observations and feedback to teachers.

ABSTRACT

Large-scale international comparative studies of teaching and learning such as the TIMSS 1999 Video Study (Hiebert et al., 2003) and the Learner's Perspective Study (Clarke, Keitel & Shimizu, 2006) offer many instances of profound differences in teacher and student behaviours in different classrooms around the world. In particular, the classroom practices of high-achieving communities frequently seem to contradict the prescriptions of empirical research conducted in Western settings. It has been argued that pedagogies in different cultures appear to be predicated on different assumptions about both the process and the product of learning in classroom settings (Clarke, 2013). These include differences in the role accorded to such things as spoken language, physical activity, and student self-regulation in the learning process. Examples from the LPS and TIMSS video projects will be used to illustrate these differences. Such findings have been interpreted as differences in sociocultural performance rather than in cognition itself, leaving unexplored the possibility that people in different cultures might learn in fundamentally different ways. Can neuroscience help us understand the variation that we find in cross-cultural classroom studies? Cross-cultural studies of teaching and learning provide both a challenge and an opportunity to determine what is truly fundamental to human learning.

INTRODUCTION

Large-scale international comparative studies of teaching and learning such as the TIMSS 1999 Video Study (Hiebert et al., 2003; Hollingsworth, Lokan & McCrae, 2003) and the Learner's Perspective Study (Clarke, Keitel & Shimizu, 2006) offer many instances of profound differences in teacher and student behaviours in different classrooms around the world. In particular, the classroom practices of high-achieving communities frequently seem to contradict the prescriptions of empirical research conducted in Western settings. It has been argued that pedagogies in different cultures appear to be predicated on different assumptions about both the process and the product of learning in classroom settings (Clarke, 2013). These include differences in the role accorded to such things as spoken language, physical activity and student self-regulation in the learning process. Such findings have been interpreted as differences of sociocultural performance rather than in cognition itself, leaving unexplored the possibility that people in different cultures might learn in fundamentally different ways.

There are also specific findings related to learning preferences and patterns of instructional practice that show remarkable consistency across cultural settings (Givvin, Hiebert, Jacobs, Hollingsworth & Gallimore, 2005). These consistencies across classrooms, whose practice reflects such different pedagogical traditions, suggest that some aspects of human learning transcend cultural context and suggest the possibility of biological or neurological rather than sociocultural explanations.

It is a key premise of this presentation that explanation of learning is possible from both sociocultural and neurological perspectives. These explanations will take different forms and appeal to different theories. In some cases, hypothesised relationships identified in one domain may assist us to understand phenomena identified as significant in the other domain. For example, the function of attention in learning may be understood neurologically, while individual inclinations to attend to some forms of stimuli rather than to others may be most usefully understood in sociocultural terms. Equally, as will be discussed, the significance attached by students across cultures to the explanations of their peers may be usefully explained in neurological terms, drawing on research into the role of empathy in facilitating learning. Importantly, the recommendations arising from such different explanatory accounts may lead to different forms of instructional advocacy.

In this discussion, we offer some of the patterns and hypotheses suggested by sociocultural analyses and pose questions about the contribution that neuroscience might make to our understanding of learning in social settings such as classrooms and the consequences for instructional advocacy of the connections we might make between explanations provided by these two research communities. Examples from the Learner's Perspective Study and TIMSS video projects will be used to illustrate the patterns and hypotheses arising from sociocultural analyses and to pose some of the questions that might be amenable to neurological investigation. Additional examples will be drawn from other fine-grained video studies. These sociocultural studies of teaching and learning provide both a challenge and an opportunity to determine what forms of explanation might best inform the promotion of learning in classroom settings.

LANGUAGE AND LEARNING

Recent cross-cultural studies of teaching and learning have problematised the exclusive advocacy of particular instructional principles. For example, a consistent message of research conducted in Australian, European and US classrooms has been the advocacy of student classroom talk as essential to effective student learning. 'Students' participation in conversations about their mathematical activity (including reasoning, interpreting, and meaning-making) is essential for their developing rich, connected mathematical understandings' (Silverman & Thompson, 2008, p. 507). Despite the emphatic advocacy in Western educational literature, classrooms in China and Korea have historically not made use of student–student spoken mathematics as a pedagogical tool (see Figures 1 and 2).

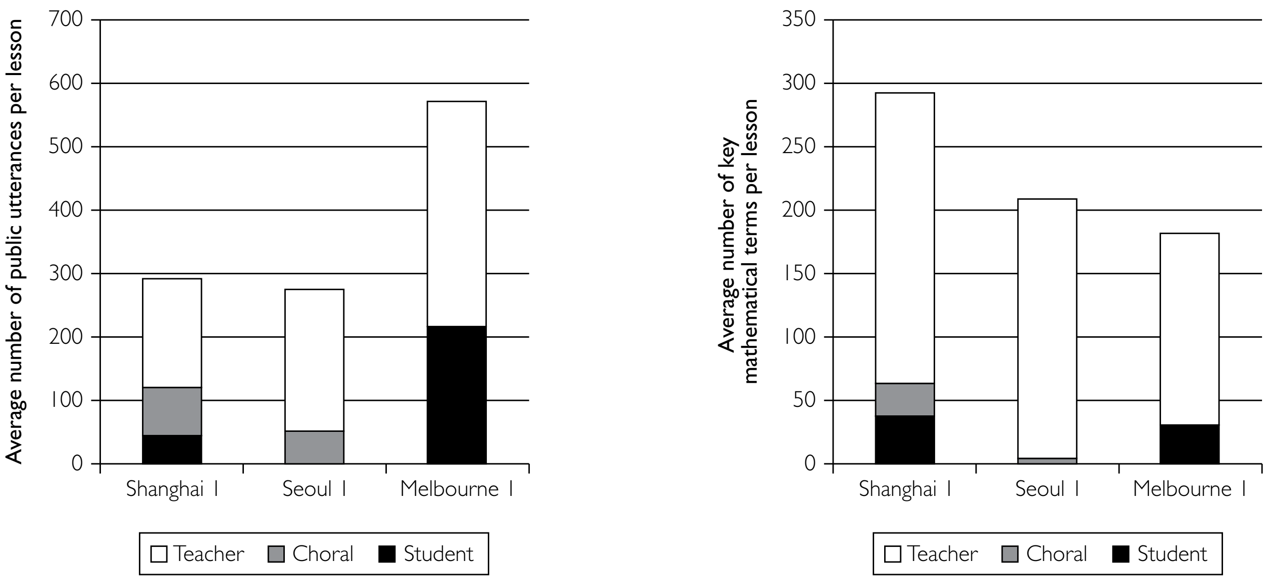


Figure 1 A comparison of public speech in three mathematics classrooms: utterances and mathematical terms, respectively (each bar represents the average of five lessons)

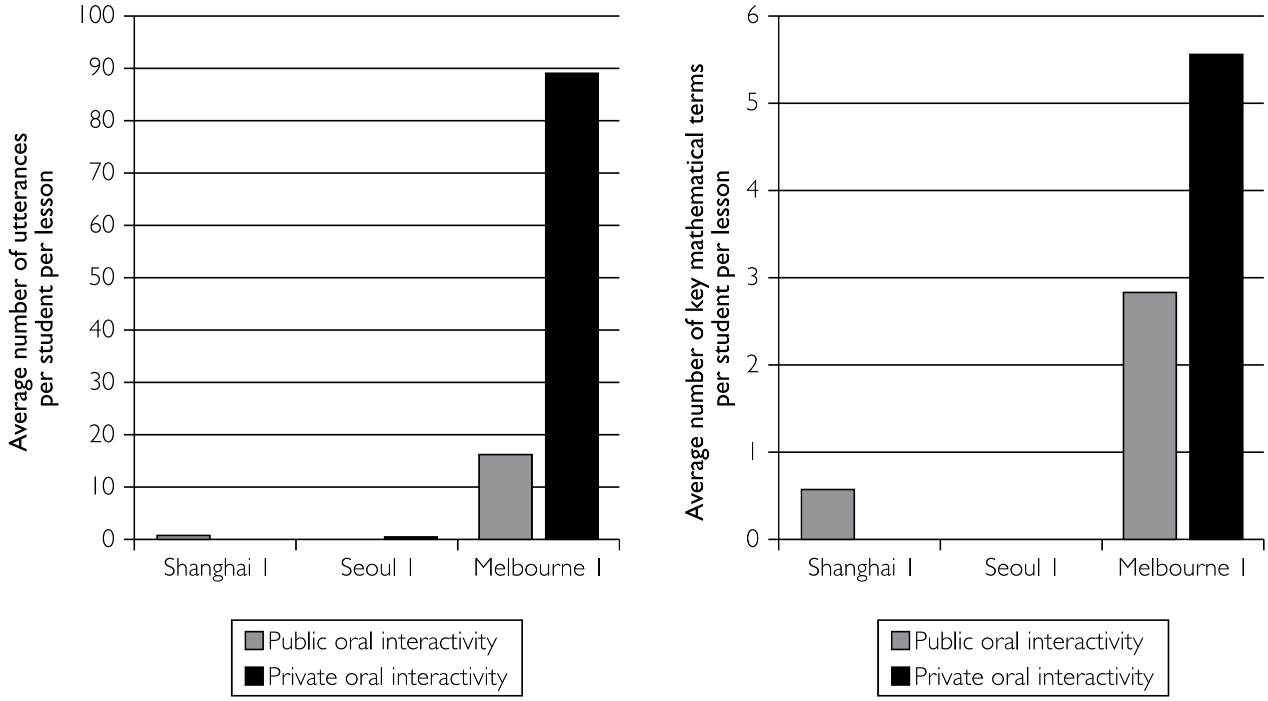


Figure 2 Comparison of public and private speech for three mathematics classrooms

As models of classroom pedagogy, these three classrooms offer quite distinct alternatives. If we focus only on public speech (Figure 1), we can see clear differences with respect to the relative proportion of teacher and student public speech and in the use of whole class (choral) response. Another significant difference is the relative prioritisation of student use of technical mathematical terms in public speech.

In research undertaken by Clarke, Xu and Wan (2010), classrooms were identified in which student fluency in the spoken use of technical mathematical terms (student spoken mathematics) was purposefully promoted in public interactions but not in private ones (for example, Shanghai classroom 1), in both public and private interactions (for example, Melbourne 1), and in neither public nor private interactions (for example, Seoul 1). Each of these classrooms enacts a distinctive pedagogy with respect to student-spoken mathematics. All three classrooms were successful in promoting student competence in completing written mathematical tasks. The students in the Shanghai and Melbourne classrooms were similar in their fluent use of technical mathematical terms in post-lesson interviews (Clarke, 2010), a capability not demonstrated by the students from the Seoul classroom.

The Korean graduates from classrooms similar to the Seoul classroom have been consistently successful in large-scale international achievement studies (TIMSS and PISA). This success appears to be achieved in classrooms that place almost no emphasis on students' spoken participation.

Despite the strident advocacy of some researchers, it appears that some forms of mathematical learning do not require student speech as an essential mediator of that learning. On the other hand, if facility with the language of mathematics is a valued outcome, it is not surprising that proficiency requires the provision of opportunities to rehearse such language use. An opportunity exists for neuroscience to help us distinguish between the types of learning that can be promoted successfully without the mediation of student speech and those types of learning that are facilitated by student speech.

REASONING, METACOGNITION AND PROBLEM SOLVING

A further question remains regarding the promotion of student mathematical reasoning, as distinct from either the ability to replicate taught procedures or to employ mathematical terminology appropriately. This is particularly of interest in situations where the problem requiring solution is unfamiliar to the individual attempting solution. In relation to such performances, it may be neither calculational proficiency nor facility with mathematical terminology that equips the problem solver for success. Instead, participation in socially enacted argumentation, where this argumentation is framed through meta-rules of discursive classroom practice (Xu & Clarke, 2013), may serve to model forms of metacognitive regulation as social rules, which the student internalises as metacognitive routines (Holton & Clarke, 2006).

In the TIMSS 1999 Video Study public release video of Japan Lesson 3, work on the first problem extended across the first 44 minutes of the lesson. The basic instructional sequence was this: teacher introduced the problem; teacher observed and assisted while students worked on the problem; teacher invited selected students to present their solutions; and teacher summarised solution methods. This teaching and learning sequence would seem familiar and unsurprising. But close analysis of the lesson video revealed a carefully crafted sequence of deliberate teaching acts that provided sophisticated scaffolding for problem solving. For example:

- the teacher devoted significant time – 4 minutes 25 seconds – to ensuring that students understood precisely what the problem was asking
- the teacher used carefully prepared diagrammatic and textual ‘props’ to demonstrate key aspects of the problem statement
- as students worked on the problem, the teacher interacted with individuals, posing questions that provided direction or provoked further thought
- as the teacher observed students at work, he noted the methods that they used to solve the problem and carefully selected students to present their solution methods. The teacher ensured that a range of methods was included and that each method was strategically positioned on the board to create a record of method types in order of sophistication. The students were asked to both write and explain their solution methods.
- as the teacher summarised the problem, he made explicit links between the different methods presented by the students and a particular method for illustrating inequalities that he introduced next.

In this example, we see Japanese pedagogy in microcosm: sophisticated teaching practice using a number of deliberate and strategic pedagogical moves.

Each constituent instructional act will have its learning consequences. Moreover, the effectiveness of the instruction will depend as much on the combination of teacher actions as on the individual acts. We look to neuroscience to help understand the learning consequences of particular teaching acts but any recommendations for classroom practice will need to take into account the social organisation of those acts and the integration of the subsequent learning products into complex student classroom performances.

Attempts to study students' metacognition have been limited by individuals' capacity to describe their thought processes. Wilson and Clarke (2004) demonstrated these limitations by eliciting students' descriptions of their thought processes while attempting mathematical tasks and then providing the opportunity for students to amend their descriptions while watching a video recording of themselves during the process of completing the mathematical tasks. In every case, students made substantial changes to their accounts of their thought processes after viewing the video. Video-stimulated reconstructive interviews can provide an additional source of explanatory or corroborative detail. Essential to the use of this methodology is the question of how similar are the thought processes stimulated by the completion of a task, the act of describing the completion of a task from memory, and the act of describing the completion of a task as a narrative annotation of a video recording. Neuroscience might usefully distinguish between the nature of the thought processes employed by students while solving a mathematical problem and the thought processes employed by the same students when reflecting on their problem solving, with and without the additional stimulus of a video recording of themselves completing the problem.

WORKED EXAMPLES AND GUIDED EXPLORATION

The use of worked examples, in which the teacher leads the class through the process of solving mathematical problems, is widespread in mathematics classrooms across cultures. Even within Confucian-heritage cultures, such as China, Japan and Korea, significant differences exist in pedagogical traditions, and the level of student spoken involvement in such worked examples has been shown to vary between classrooms. Recent comparisons of the practices of selected classrooms in Shanghai, Seoul and Tokyo (all Confucian-heritage cultures) revealed substantial differences (Clarke, Xu & Wan, 2010; Xu & Clarke, 2013).

With respect to the nature of the mathematical tasks employed, the Korean classroom was characterised by student attentive (but passive) observation of the teacher's completion of worked examples. The Shanghai classroom involved extensive public discussion of worked examples, emphasising correct use of mathematical terminology. The Japanese classroom placed much greater emphasis on student exploratory completion of mathematical tasks that had frequently not been modelled as worked examples by the teacher. Student engagement in such guided exploration is illustrated in the following conversation between two Japanese students engaged in dyadic problem solving.

KAWA [TO WADA]: I managed to draw that line!

WADA: Like this?

WADA [TO KAWA]: If you draw that line over the *middle point* [mid-point], isn't that the answer, Kawa?

KAWA: Oh, I don't think so!

WADA: I think you don't have to do such a thing. I think you just have to draw a line from *P*.

KAWA: I don't really understand what you mean.

WADA: Um, you drew a *middle point* [mid-point] here, right? So if you just draw a line from here, wouldn't that do?

KAWA: Can you draw a line from *P*?

WADA: Yes. If you draw a line from there, if goes over the *middle point* [mid-point] so there is no problem there.

KAWA: What was the name of the *theorem* again?

WADA: *Middle point* [Mid-point] *connection theorem*.

KAWA: That's it! But it isn't *parallel* there. Are you going to try drawing it there?

WADA: Draw a *parallel line*.

KAWA: Did so.

WADA: Well, it's not going over *P* if you notice.

KAWA: And which one's the same here? Tell me.

WADA: These two are *parallel*.

KAWA: Where's the *bottom line* [base] then?

WADA: This is the *bottom line* [base], I bet. God, I don't know which one is the *bottom line* [base] now.

KAWA: This one has to be the *bottom line* [base].

WADA: This has to be the (height), this one. This is the *height*. I got it now!

KAWA: Is this the *height*? Is it all right if it's now *parallel*?

WADA: Well, it doesn't have to be *parallel*. No need for that.

KAWA: But then which two become equally in half?

WADA: What the hell are you saying?

KAWA: Aren't we doing the one that we have to divide in half or something like that?

WADA: Yes, that's the one we're talking about.

KAWA: I'm starting to get mixed up now.

WADA: Well, I'm starting to get a headache. (Sample student–student 'private' interaction – Classroom transcript, Learner's Perpsective Study, Tokyo School 2 – lesson 2, 29:46:12 – 33:15:19.)

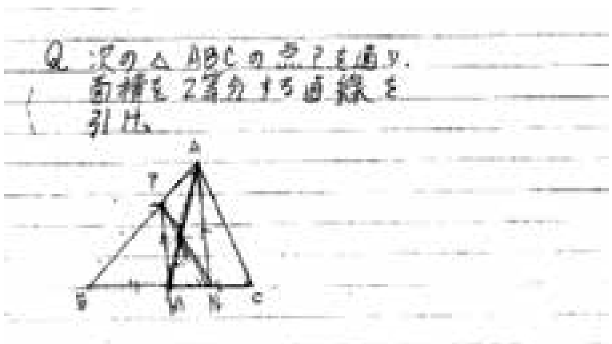


Figure 3a Wada's work

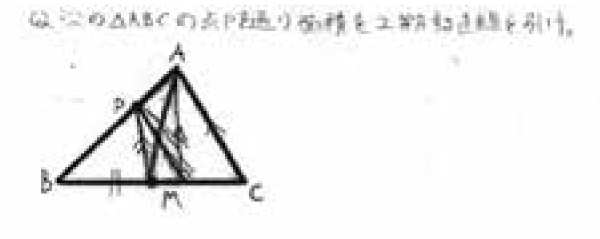


Figure 3b Kawa's work

In Figures 3a and 3b, we can see the problem representations constructed by each student. Such representations have their own role in the learning and problem-solving process and warrant specific investigation. Such dyadic interaction is a social performance with the purpose of completing a given mathematical task or problem. The nature of student cognition during such interaction warrants much closer study for several reasons:

- the difference between individual problem-solving and dyadic problem-solving as facilitators of student learning distinguishes important pedagogical alternatives in widespread use
- the learning consequences of student observation of a worked example by the teacher compared with the student's use of a taught procedure to solve a familiar problem, compared with a student's attempt to develop a procedure to solve an unfamiliar problem require detailed empirical explication
- explanations of reasoning provided by students (as distinct from teachers' explanations) were identified as significant by students in all cultures in which such explanations occurred.

A very different instructional approach employed in the Czech Republic integrates both the apparent power of the worked example and student explanation. In mathematics classrooms in the Czech Republic a common instructional event at the beginning of lessons is a practice known as 'oral grading'. This involves selected students completing mathematical problems related to the current topic on the board in front of the class, while being graded by the teacher. The students are required to write their solution methods on the board and explain the process they are working through to their fellow students. The purpose is for the teacher to determine students' level of knowledge. The teacher of Czech Lesson 1 from the TIMSS 1999 Video Study (public release collection) noted in her commentary:

> *None of the students know which one will be called up to the board. I want them to present their knowledge by commenting, explaining to their fellow students, and writing it on the board.*

While the selected student works on the problem set by the teacher, other students in the class work on the same problem at their desks. Those students may work independently or follow the student working at the board. Teachers regard this time as an opportunity for all students to engage in review. It is our contention that this strategy provides a powerful stimulus to learning through its combination of the worked example and student explanation, both of which have proved demonstrably effective in our studies of Asian classrooms.

Neuroscience may be able to assist in distinguishing the forms of learning (in neurological terms) arising from differences in student experience in classrooms such as these and also provide explanations for the relative effectiveness of such different instructional strategies in producing particular learning outcomes.

CONCLUSIONS

In this discussion, we have attempted to illustrate some of the challenges confronting those interested in researching learning in classroom settings. The examples were chosen because they highlight significant findings arising from sociocultural classroom research and seem to us to be amenable to further investigation using the tools of neuroscience. At the same time, each example offers significant methodological challenges if it were to be investigated from a neurological perspective. In each example, the complexity of the social situation is evident. If we think of the sociocultural and neuroscience perspectives as offering complementary accounts of such complex social phenomena, then it is clear that we are connecting very different research paradigms.

The techniques of neuroscience inevitably require a high level of specificity of research design with respect to the stimuli provided to the learner and the form in which any consequent learning can be recorded and interpreted. By contrast, consider the sort of complex social phenomena illustrated in this presentation:

- the role of the learner's spoken participation in classroom discourse in mediating learning
- the strategic, structured sequence of instructional acts, supported by selected artefacts, that, in combination, constitute a learning activity or a lesson
- the nature of student thinking when engaged in problem solving, undertaken as members of dyadic or small group social interactive units and the learning associated with this activity
- the function of both student explanation and worked examples, separately or together, in triggering student learning responses.

Our interest in these particular classroom examples is a direct consequence of the consistent significance attributable to each classroom phenomenon across a variety of cultural settings.

Such sociocultural phenomena cannot be meaningfully reduced to component instructional acts if our goal is to understand learning consequences of complex instructional activities, reflective of coherent, connected and culturally situated systems of pedagogy. If our aim is to identify the neurological consequences of each separate instructional act, then it may be possible to identify the key characteristics of such instructional acts with sufficient precision as to make each characteristic the focus of a clinical experiment designed to identify the learning consequences of the particular act in terms of either brain activation or neural networks. It is entirely possible that the effectiveness of the activity as a whole does not derive from the individual acts but from the cumulative interaction of their sequenced deployment by a teacher cognisant of the needs and capabilities of the particular learners. Nonetheless, while the neurological consequences of the disconnected instructional acts may not (even in combination) provide a coherent explanation for the effectiveness of the aggregate instructional activity, it is possible that neuroscience may have something to say about how the learning mechanism associated with each act and the means by which its effects might be optimised.

A challenge for any research project seeking to connect sociocultural research with neuroscience is how to interweave the complementary accounts provided by each analytical approach. We suggest that, in the same way that the unit of analysis is different between sociocultural and neuroscience research, so the nature of the explanations provided will be fundamentally different, offering not different explanations of the same phenomenon but explanations of related phenomena that are different in scale, in complexity and in the relative prominence given to the individual as cognising agent or as participant member of a social group. We anticipate drawing on the findings of one discipline to explicate, elaborate and explain learning as it is conceived in the other discipline. In studying instruction and learning in different classrooms around the world, we have found that the tensions and apparent contradictions that appear to pose the greatest challenge for useful interpretation and instructional advocacy also provide the greatest insight. A research partnership between sociocultural and neurological approaches should generate similar challenges, which on close examination will be seen as opportunities for significant insight into learning as a social and an individual phenomenon.

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THE BENEFITS OF MUSIC FOR THE BRAIN

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Sarah is recognised for pioneering music neuroscience and music neuro-imaging research in Australia, as well as characterising a new clinical syndrome after the successful treatment of chronic disease. She has significant expertise in the cognitive and psychosocial assessment of brain-injured and healthy individuals using behavioural and neuro-imaging techniques, with a view to improving psychological treatments for cognitive, psychosocial and emotional disorders. Since the commencement of her career she has been awarded continual nationally competitive funding (totalling approximately $6 million) to support her work and that of her team, and has supervised 78 graduate students and four post-doctoral fellows. She has 90 peer-reviewed scientific publications, which have received more than 1400 citations to date. She is currently an associate editor of *Frontiers in Auditory Cognitive Neuroscience*, and a member of the editorial board of *Epilepsy and Behavior*. She is regularly invited to present keynote addresses, chair symposia, and give media interviews internationally and around Australia (more than 120 in total), and to date her research and that of her team has received two national and four international prizes.

ABSTRACT

While it is clear that the power of music reflects its ability to activate the emotional and reward networks of the brain, its influence extends beyond this through its capacity to integrate multiple brain systems in the unified act of music making. This integrative role may endow music with unique benefits not inherent in other activities, underscoring its evolutionary significance. There are now more than 100 neuro-imaging studies showing that music activates multiple brain networks during music listening, responding and performance. As a result, when we compare musicians and non-musicians there are substantial differences in size, shape, density, connectivity, and functional activity that occur extensively throughout the musician's brain. It is not surprising then, that music has been dubbed the 'food of neuroscience', and provides a powerful model of how the brain can change in response to the environment. This discussion examines some of the core principles of brain plasticity derived from cognitive neuroscience, and the way in which music behaviour exemplifies these. It also considers how the brain can change in response to music and the broad range of cognitive processes and behaviours this may affect. Powerful amongst these is the ability of music to prime the brain for future learning, while more broadly promoting our individual and social wellbeing.

MUSIC MAKING INTEGRATES MULTIPLE BRAIN SYSTEMS

> *Playing, listening to and creating music … involves a tantalizing mix of practically every human cognitive function. (Zatorre, 2005, p. 312)*

Music occurs in every human society and forms part of our basic human design. In a paper entitled 'Music, the food of neuroscience?' Robert Zatorre proposed that music research

> *is beginning to illuminate the complex relation between cognitive–perceptual systems that analyse and represent the outside world, and evolutionarily ancient neural systems involved in assessing the value of a stimulus relative to survival and deciding what action to take. (2005, p. 315)*

This quote alludes to an emerging idea that music, as an art form, provides entry to an experience in which the many and varied functions of our mind can become integrated through the unified act of music making. This act is underscored by activation of the evolutionarily ancient reward system of the brain (the dopaminergic mesocorticolimbic system) that has a critical role in mediating arousal and attention, emotion, motivation, learning, memory and decision making. Both within an individual and between individuals, the concurrent activation of these multiple brain systems is presumably synchronised by the structure and temporal flow of music. This experience may underpin the personal and social power often ascribed to music, anecdotally described as experiences of transcendence or 'flow'. It also points to the adaptive and evolutionary significance of music, in terms of its multiple benefits for human learning and development.

As a complex task, music making provides a wealth of opportunities to study brain structure and function across multiple information processing systems, using both bottom-up and top-down approaches. Additionally, it allows investigation of isolable components or networks in either the intact or damaged brain in the context of specific parameters that may shape these networks. These include developmental factors fundamental to learning, such as the age when music training begins, or the extent of training to promote expertise. At present, our understanding of the multiple systems involved in listening to, responding to and performing music is based on the findings of more than 100 neuro-imaging studies that have been conducted with musicians and non-musicians (see Merrett & Wilson, 2011, for a detailed review), as well as behavioural and neuropsychological studies dating back more than 100 years (for example, see Stewart, von Kriegstein, Warren & Griffiths, 2006). Broadly, these findings indicate that music making draws on a range of highly developed and well-integrated sensory, perceptual and motor skills, as well as emotions, memory, and higher order cognitive and attentional functions (see Table 1). The motivation to engage in this complex state is driven by the reward system of the brain that activates in response to both the anticipation of and the experience of pleasure (Salimpoor, Benovoy, Larcher, Dagher & Zatorre, 2011). When combined with enhanced imitation or synchronisation with others (Spilka, Steele & Penhune, 2010), this may promote emotional sensitivity, empathy and social cognition (Hallam, 2010).

The well-established neuroscience and behavioural literature surrounding music making offers a strong platform from which to explore its many and varied reported benefits. Stated simply, this platform is based on the observation that music makes connections at multiple levels, including the following:

- the level of the brain, in terms of its structure and function
- the level of the mind, for transfer of cognitive skills that are shared or similar
- at a personal level, in terms of integrating our thinking and emotions and regulating our wellbeing
- at a social level, for building social cohesion.

These connections have been shown to translate to academic benefits, including improved literacy, numeracy, spatial abilities, executive functioning and intelligence, as well as greater school attendance and participation. They also extend to psychological benefits for self-confidence and self-discipline, and social benefits for teamwork and social skills (Hallam, 2010; Rickard & McFerrin, 2011).

Table 1 Information processing systems engaged by music making

Highly developed sensory processing	Multi-modal: auditory, visual, tactile, kinesthetic
Auditory perceptual processing	Auditory recognition, fine-grained pitch perception, auditory streaming and syntactic processing
Fine-motor skill learning	Bimanual coordination, digit and vocal control
Sensory-motor integration	Performance monitoring and correction
Visual and spatial processing	Visuo-spatial perception, mental rotation and spatial awareness
Executive functions and attention	Auditory and spatial working memory and imagery, selective and sustained attention, planning, creativity, problem solving and decision making
Emotional processing	Emotional awareness and expression, anticipation and the experience of reward
Memory processing	Procedural, semantic and episodic memory, including autobiographical memory
Social cognition	Imitation and empathy, theory of mind

This table summarises key findings in the literature and is not intended as an exhaustive list. The area of social cognition has received limited research attention.

MUSIC MAKING EPITOMISES CORE PRINCIPLES OF NEUROPLASTICITY

> *The large amount of natural variation in the training, practice, and skill acquisition of musicians creates a 'formidable laboratory' for studying experience-dependent neuroplasticity. (Peretz & Zatorre, 2005, p. 102)*

The adaptive capacity of the central nervous system, otherwise known as neuroplasticity, is considered to underpin learning in the intact brain, as well as relearning in the damaged brain. It is now well established that neurons and other brain cells, 'possess the remarkable ability to alter their structure and function in response to a variety of internal and external pressures, including behavioral training' (Kleim & Jones, 2008, p. S225). This implies that neuroplasticity is the brain mechanism used to encode experience and to repair itself by means of morphologic and physiologic responses. These responses are commonly studied at the level of change in expressed neurotransmitters of neurochemical systems, and at the level of cell assemblies or networks in terms of changes in brain morphology and patterns of connectivity.

In a recent review, Kleim and Jones (2008) identified 10 fundamental principles of neuroplasticity that have derived from decades of basic neuroscience research (see Table 2). These principles do not constitute an exhaustive list but have rather been chosen to highlight factors relevant to experience-dependent neuroplasticity in models of learning and recovery from brain damage. The obvious applicability of these principles to music making is clear and, for the sake of argument, they have been expressed in terms of training in Table 2. In fact, training in music making has been hailed as an ideal model for examining experience-dependent neuroplasticity as it embodies many of the prerequisites for inducing neuroplasticity: repetition of, intensity of and specificity of training against a background of high emotional salience and reward.

Table 2 Core principles of experience-dependent neuroplasticity

Use it or lose it	Neural networks not actively engaged in training can degrade
Use it and improve it	Training can induce dendritic growth and synaptogenesis within specific brain regions that enhance task performance
Specificity	The nature of training dictates the nature of the plasticity
Repetition matters	Repetition is required to induce lasting neural change (skill instantiation)
Intensity matters	A sufficient intensity of stimulation is required to induce plasticity
Time matters	Different forms of plasticity occur at different times during training
Salience matters	The training experience must be sufficiently rewarding to induce plasticity
Age matters	Training-induced plasticity occurs more readily in the younger brain
Transference	Plasticity induced by one training experience can enhance the acquisition of similar behaviours
Interference	Plasticity induced by one training experience can interfere with the acquisition of similar behaviours

This table summarises key principles identified by Kleim and Jones (2008) and is not intended as an exhaustive list.

THE MUSICIAN'S BRAIN AS A MODEL OF NEUROPLASTICITY

The heterogeneity of music training and skills in the general population provides a distinct advantage for researchers seeking to understand the mechanisms of experience-dependent neuroplasticity. Varying the task, the level of training, age of commencement and instrument played create many permutations and combinations from which precise experiments can be designed to answer a range of questions about the adaptation of the human brain. Already, this has identified a number of salient variables that appear to moderate the relationship between music training and neuroplasticity. In keeping with the core principles of Kleim and Jones, these include the age when training begins, the presence of the specific skill of absolute pitch and the exact instrument studied, as well as sex differences (Merrett & Wilson, 2011).

It has been repeatedly shown that the brains of musicians are differently organised from those of non-musicians, particularly if training began early in life. There are substantive differences in size, shape, density, connectivity and functional activity that occur extensively throughout the musician's brain, most notably in frontal, motor and auditory regions (Merrett & Wilson, 2011). Early training effects have been attributed to the benefits of environmental enrichment on the developing brain as well as its enhanced capacity for neuroplasticity, especially during sensitive periods when specialised skills may develop, such as absolute pitch (Wilson, Lusher, Martin, Rayner & McLachlan, 2012). It is also the case that different musical instruments provide unique sensory and motor experiences and can lead to differences in the type and location of neuroplastic changes (Bangert & Schlaug, 2006).

Notably, the first *in vivo* evidence of structural modification of the musician's brain was reported by Schlaug and colleagues, who observed a larger anterior corpus callosum in musicians who commenced early training (before the age of seven) (Schlaug, Jancke, Huang, Staiger & Steinmetz, 1995), and greater leftward asymmetry of the planum temporale in musicians with absolute pitch (Schlaug, Jancke, Huang & Steinmetz, 1995). The corpus callosum supports information transfer between the two cerebral hemispheres while the planum temporale is crucial to language and music processing. Subsequently, structural differences were demonstrated in many other brain regions, including sensori-motor and auditory cortices, the inferior frontal gyrus, the cerebellum and white matter tracts. These differences are generally bilateral and greater in musicians, as shown in Figure 1.

Commensurate with structural brain differences, music training has been linked to differences in brain function. While music processing typically engages the functioning of both cerebral hemispheres in musicians and non-musicians, there is evidence of increased left hemisphere specialisation in musicians for some tasks. These include passive music listening (Ohnishi et al., 2001), rhythm perception (Limb, Kemeny, Ortigoza, Rouhani & Braun, 2006) and imagined singing (Wilson, Abbott, Lusher, Gentle & Jackson, 2011), with the extent of left lateralisation potentially influenced by sex differences (Koelsch, Maess, Grossmann & Friederici, 2003). Generally speaking, differences in brain function have supported enhanced information processing and superior integration across different modalities in musicians, accompanied by more focal or efficient activation in functional imaging studies (Merrett & Wilson, 2011).

Enhanced information processing is evident in musicians even at early stages of processing for a variety of auditory stimuli, including clicks, tones, music and speech. This confers an advantage for encoding sound features, such as pitch and timing (McLachlan & Wilson, 2010), as demonstrated by superior auditory detection, pitch and temporal discrimination, and music and language processing in musicians (Merrett & Wilson, 2011). The sensory and motor systems of musicians also appear more tightly coupled particularly in musicians with early training, even after years of training, amount of music experience and current practice have been taken into account (Watanabe, Savion-Lemieux & Penhune, 2007). This superior sensori-motor integration is most evident for motor synchronisation tasks, which require the integration of motor information across multiple sensory modalities. Such cross-modal integration enhancements may vary between different types of musicians, depending on the instrument played (Merrett & Wilson, 2011).

Functional imaging studies have generally shown that while singing, playing instruments and improvising, musicians have more efficient representations and use fewer neural resources than non-musicians (Merrett & Wilson, 2011). Since these patterns of activation are typically accompanied by superior motor performance, they are considered to reflect greater recruitment of regions pertinent to task performance and decreased activation of areas that provide secondary support. These findings converge with transcranial magnetic stimulation studies that suggest enhanced motor information transfer along white matter tracts, such as the corpus callosum (Ridding, Brouwer & Nordstrom, 2000). More generally, there is good consistency between the structural, functional and behavioural differences found between musicians and non-musicians, confirming the presence of widespread neuroplastic changes associated with music training. These widespread changes have been supported by a number of recent longitudinal studies that show that music training can causally induce experience-dependent neuroplasticity across the lifespan (Hyde et al., 2009; Stewart et al., 2003), as well as enhance the capacity for further learning and neuroplasticity (Ragert, Schmidt, Altenmüller & Dinse, 2004; Rosenkranz, Williamon & Rothwell, 2007) in both healthy and brain injured individuals (Schlaug, Marchina & Norton, 2009).

MUSIC MAKING 'PRIMES' THE BRAIN FOR LEARNING

Through the core principles of neuroplasticity, the brain continually remodels its neural circuitry to encode new experiences and support behavioural changes that guide learning in the healthy and damaged brain (Table 2). These principles highlight that not only early music training but also its accumulation and recency

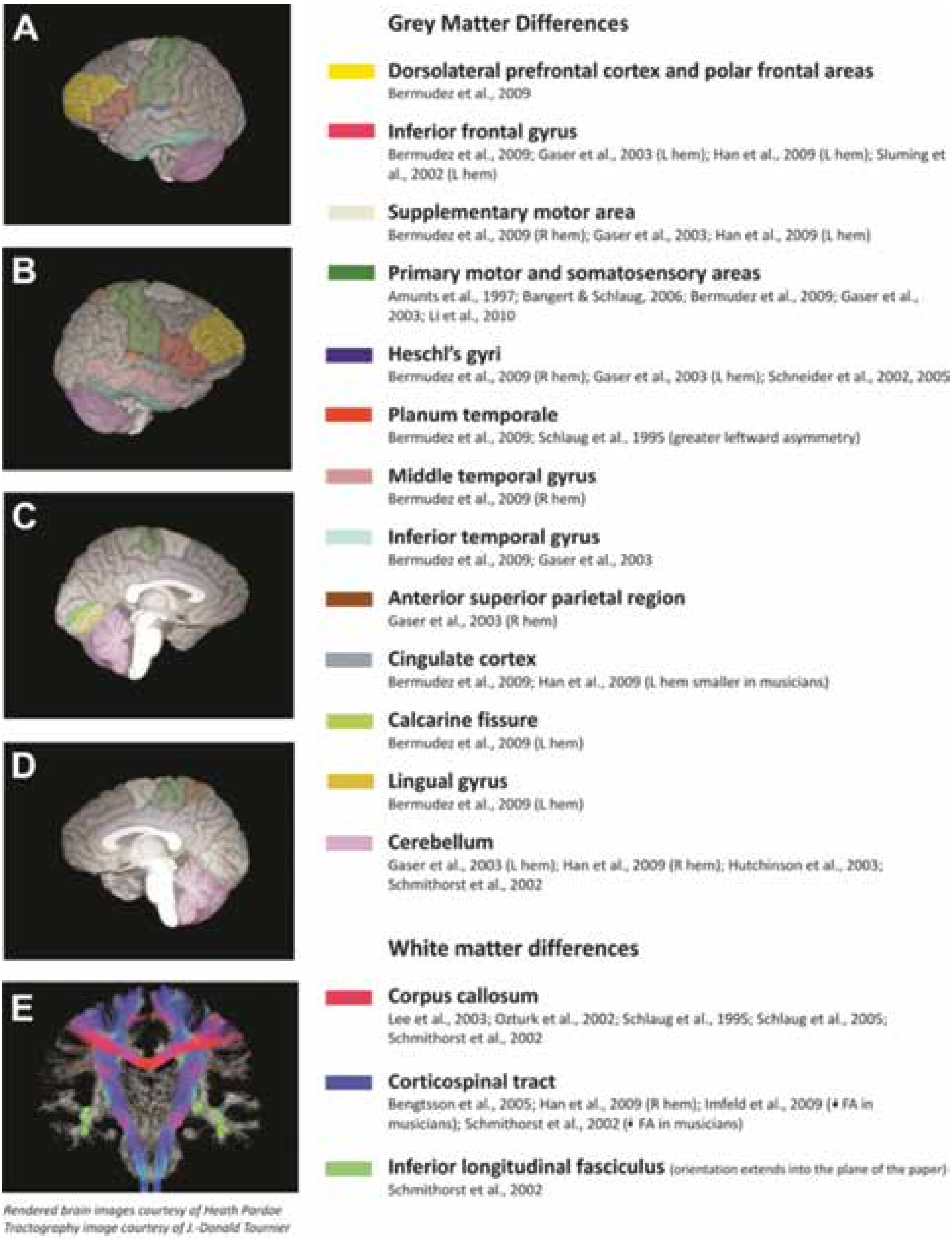

Figure 1 Approximate locations of structural brain differences in musicians compared to non-musicians for the left hemisphere (A lateral, C medial), right hemisphere, (B lateral, D medial), and white matter tracts (E). All differences are bilateral unless otherwise noted (L hem = left hemisphere; R hem = right hemisphere; FA = fractional anisotropy). Figure courtesy of Merrett & Wilson (2011).

can moderate the extent of brain plasticity. This raises a question about the stability of training-induced changes in the brain, and whether ongoing music training is required to maintain such changes. For example, would significant changes in the structure of the brain induced by early training remain even if music training ceased shortly afterwards? Studies outside the music domain have suggested that structural changes in the brains of adults can occur within one week of training on a complex motor task (for example, juggling), but return to baseline without ongoing training (Draganski et al., 2004; Driemeyer, Boyke, Gaser, Büchel & May, 2008). These studies also suggest that it is the act of learning the task rather than ongoing practice or maintenance of the task that induces neuroplasticity. For example, Driemeyer and colleagues (2008) found that within the first seven days, juggling training led to neuroplastic changes, whereas ongoing practice over the following month (with associated skill improvement) did not induce further plasticity. This suggests that different outcomes may follow learning methods that focus on training new tasks as opposed to repeated practice of learned tasks. Although the terms 'training' and 'practice' are often used interchangeably, perhaps these terms should be differentiated to indicate whether a learning paradigm includes novel, challenging tasks with corrective feedback (training) or repetition without external feedback (practice). This is important because neurobiological differences may exist between music 'training' and 'practice'.

Even before music training occurs, environmental differences may play a role in future training-induced changes in the brain. For example, a study in preschool children indicated that having more music exposure (such as another musician in the home) led to differences in auditory functioning that were already evident before training (Shahin, Roberts & Trainor, 2004). Moreover, a number of studies now suggest that the musician's brain seems more capable of neuroplastic change (Herholz, Boh & Pantev, 2011; Ragert et al., 2004; Rosenkranz et al., 2007; Seppanen, Hamalainen, Pesonen & Tervaniemi, 2012; Tervaniemi, Rytkönen, Schröger, Ilmoniemi & Näätänen, 2001). This phenomenon is known as 'meta-plasticity' and occurs when the activity of the brain regulates the expression of future plasticity at the level of both individual neuronal connections and connections between brain regions (Abraham, 2008). It suggests that plasticity begets plasticity, and that previous music exposure primes the brain for future learning. This supports the observation that training in music can influence learning in other fields, providing a potential mechanism for 'near transfer' effects, and the broader cognitive and behavioural benefits of engaging the brain in music.

CONCLUSIONS

From the perspective of neuroscience, music making has much to offer our understanding of the brain and the way its multiple systems can interact to produce benefits for mental health and social wellbeing, both by integrating our thinking and emotions and helping us to connect with others. Music provides a powerful tool to enhance learning because of its widespread effects on the brain and its ability to induce experience-dependent neuroplasticity. By harnessing the many and varied benefits of music making, it can create an enriched environment to stimulate the fundamental capacity of the brain to adapt to the ever-changing environment, thereby promoting our individual and social development. While not exhaustive, this discussion has attempted to draw together some key perspectives recently emerging from the field that are informed by advances in basic neuroscience research. These advances will continue to shed important insights into the power of music to integrate the mind and body and to heal the brain through the unified act of music making.

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POSTER PRESENTATIONS

1 MS ANN WILLIAMS
Deakin University

A TEACHER'S PERSPECTIVE OF DYSCALCULIA: WHO COUNTS?

Dyscalculia is one of the many reasons children have difficulties with mathematics. The literature on its remediation is in its infancy. The potential for multidisciplinary research is great but would require maths educators to become involved, where previously they have been silent. As well as knowing what dyscalculia is, teachers need to understand its causes and have effective strategies to deal with it. Teachers also need to know how dyscalculia affects a child's self-belief system in order to counter the effects of poor self-esteem, maths anxiety, and so on. There is an incidence rate of 5 per cent in Australian schools, yet there is a lack of recognition, identification and diagnosis of dyscalculia despite the fact that the behavioural characteristics of dyscalculia are generally agreed on. The reasons that the diagnosis is masked could be the existence of another (possibly previously diagnosed) specific learning disability: for example, 50 per cent of dyslexics have dyscalculia.

2 DR JEAN THOMPSON
radii.org, Victoria

USING FEEDBACK TO IMPROVE TEACHING AND LEARNING OF HIGHER ORDER SKILLS

Radii has developed 'Educational Intelligence' as an advanced data capture and reporting system to meet the specific needs of the education and training sector. Educational Intelligence uses an artificial intelligence (AI) approach that allows users to develop and run 'best practice' surveys. The AI systems engage the user in dialogue in ordinary language to determine the user's requirements, which are then translated into the survey and management processes via the AI engines. The AI engine reads meta-data about each question, undertakes statistical analyses and builds a report. The poster will demonstrate an example of using a survey to evaluate the challenges and appropriateness of thinking in high-ability classrooms.

3 DR PINA TARRICONE
Centre for Schooling and Learning Technologies, Edith Cowan University, Western Australia

DEVELOPMENT OF A COGNITIVE TOOL TO HELP UNDERSTAND THE CONSTRUCT OF METACOGNITION

This poster demonstrates a cognitive learning tool, in development, that uses the Taxonomy of Metacognition as the basis of the tool (Tarricone, 2011). The taxonomy provides a clarification of the construct of metacognition. It is a structure that categorises the construct providing a framework. The cognitive tool is based on a concept-mapping structure to depict knowledge representations of metacognition as presented in the taxonomy. Research on the brain suggests that it organises and develops structures and interconnected networks of information (Sylwester, 2005). The aim of the cognitive tool is to facilitate knowledge construction about the structure of the construct of metacognition. The tool will help to provide a dynamic clarification of the construct for teachers and researchers. It is also intended that the tool will be a vehicle for future quantitative research using Rasch (1960) methodologies.

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4 MS JEANIE BEH
Swinburne University of Technology, Victoria

INTEREST IN THE LEARNING OF TOUCH TECHNOLOGIES BY OLDER ADULTS

This research explores the role of interest in the adaptation of mobile touch technologies by older adults, extending existing research about andragogy (learning for adults) and geragogy (learning for older adults). We are applying existing frameworks for interest in early learning for older adults in learning to engage with touch technologies. A key interest is how existing frameworks for interest in early learning can be extended specifically for older adults in learning to use touch technologies and also to explore the influence of interest and technology use upon neuroplasticity in geragogy. We employ a combination of quantitative and qualitative research methods such as questionnaires, interviews, observations and neuro-imaging (MRI) data. This study is in collaboration with local community centres and organisations and their clients (ranging between 60 and 90 years of age). The poster will show first results and implications of interest on learning and brain activity of older adults.

5

MR NICK RILEY
University of Newcastle, New South Wales

OUTCOME PROCESS EVALUATION OF A PROGRAM INTEGRATING PHYSICAL ACTIVITY ACROSS THE PRIMARY SCHOOL CURRICULUM: ENCOURAGING ACTIVITY TO STIMULATE YOUNG MINDS (EASY MINDS)

The poster will present preliminary findings of the EASY Minds study. The program uses movement-based learning as a novel strategy to enhance academic achievement, physical levels and on-task behaviour.

6

DR JOHN WILLISON AND CHRISTINA SURMEI
School of Education, University of Adelaide

WIRED TO INQUIRE

Early childhood is the time when the development that happened in utero and the world surrounding the child meet to create new knowledge and understandings through personal self-initiated inquiry (Willison, in press). Such spontaneous inquiry can be considered an innate occurrence, connecting biological function, the physical world and the socially constructed world (Zeanah, 1996). Educators document how young children use their constructed play environments to inquire and question their world, providing data that is rich in detail about a child's proximodistal and cephalocaudal development (Berk, 2010). An example of this is an 11-month old infant who, although preverbal, points to objects all around the play environment to provoke a statement from the carer about the name of each object. This answers the young child's personal self-initiated inquiry, through 'cause and effect', just like the game, 'Peek-a-Boo' (Berk, 2010). This poster will consider multiple factors that equip young children to be, neurologically, wired to inquire.

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CONFERENCE PROGRAM

PROGRAM

Sunday 4 August

6.00 – 7.30 pm — **Welcome Reception, Level 1 Foyer**, Melbourne Convention & Exhibition Centre

Monday 5 August

8.00 – 8.45 — Registration

8.45 – 9.00 — Welcome to Country

9.00 – 9.15 — Pizzicato Effect, Meadows Primary School and The Melbourne Symphony Orchestra

9.15 – 9.30 — **Conference Opening**, Professor Geoff Masters, CEO, ACER

9.30 – 10.45 — **Plenary 1 – Our Learning/Teaching Brains: What can be expected from neuroscience, and how? What should not be expected, and why?**
Dr Bruno della Chiesa *(Harvard University, USA)*
Chair: Professor Geoff Masters *(ACER)*

10.45 – 11.15 — Morning Tea

11.15 – 12.30 — **Concurrent Sessions Block 1**

Session A	Session B	Session C	Session D	Session E
105	**103**	**101 & 102**	**104**	**Plenary**
When the Educational Neuroscience meets the Australian Curriculum: A strategic approach to teaching and learning Professor Martin Westwell *(Flinders University)* Chair: Mr Lance Deveson *(ACER)*	***Measuring Learning in Complex Learning Environments*** Dr Mike Timms *(ACER)* Chair: Mr Steven Dover *(ACER)*	***The Brain, Early Development and Learning*** Associate Professor Michael Nagel *(University of the Sunshine Coast)* Chair: Ms Debbie Lee *(ACER)*	***A Pedagogical Decalogue: Discerning the practical implications of brain-based learning research on pedagogical practice in Catholic schools*** Dr Dan White *(Catholic Education Office, Sydney)* Chair: Mr Peter McGuckian *(ACER)*	***From Brain Research to Design for Learning: Connecting neuroscience to educational practice*** Professor Peter Goodyear *(University of Sydney)* Chair: Dr Kate Reid *(ACER)*

12.30 – 1.30 — Lunch

1.30 – 2.45 — **Plenary 2 – The Woman Who Changed her Brain**
Ms Barbara Arrowsmith-Young *(Arrowsmith Program, Canada)*
Chair: Dr Dan White *(Catholic Education Office, Sydney)*

2.45 – 4.00 — **Concurrent Sessions Block 2**

Session F	Session G	Session I	Session J	Session K
103	**Plenary**	**104**	**101 & 102**	**105**
Debunking the Pseudoscience Behind 'Boy Brains' and 'Girl Brains' Associate Professor Cordelia Fine *(The University of Melbourne)* Chair: Dr Sarah Richardson *(ACER)*	***Building the Realities of Working Memory and Neural Functioning into Planning Instruction and Teaching*** Professor John Pegg *(University of New England)* Chair: Ms Marion Meiers *(ACER)*	***From the Laboratory to the Classroom: Translating the learning sciences for use in technology-enhanced learning*** Dr Jason Lodge *(Griffith University)* Chair: Ms Blanca Camacho *(ACER)*	***Learning and Fearing Mathematics: Insights from psychology and neuroscience*** Dr Sarah Buckley & Dr Kate Reid *(ACER)* Chair: Mr Ben Dawe *(ACER)*	***High-Ability Learning and Brain Processes: How neuroscience can help us understand how gifted and talented students learn and the implications for teaching*** Associate Professor John Munro *(The University of Melbourne)* Chair: Ms Jacqueline Moore *(ACER)*

6.30 pm (7 pm start) — Conference Dinner

Tuesday 6 August

9.00 – 10.15 Plenary 3 – Minds, Brains and Learning Games
Dr Paul Howard-Jones *(University of Bristol, UK)*
Chair: Dr Mike Timms *(ACER)*

10.15 – 10.45 Morning Tea

10.45 – 12.00 Concurrent Sessions Block 3

Session L	Session M	Session N	Session O	Session P	Session Q
106	**104**	**Plenary**	**101 & 102**	**105**	**103**
Learning, Remembering and Forgetting in the Mammalian Brain Professor Pankaj Sah *(The University of Queensland)* Chair: Mr Ralph Saubern *(ACER)*	***From Experimental Psychology to a Science of Learning*** Professor Ottmar Lipp *(The University of Queenland)* & Dr Sacha DeVelle *(ACER)* Chair: Dr Sarah Buckley *(ACER)*	***Being the Best Learner You Can Be: Translating research into educational practice*** Ms Donna Nitschke *(Neuroscience in the Classroom, SA)* Chair: Ms Barbara Smith *(ACER)*	***Do Boys and Girls Read Differently Online? Evidence from PISA 2009 Digital Reading Assessment*** Ms Dara Ramalingam, Ms Juliette Mendelovits, Dr Tom Lumley *(ACER)* Chair: Ms Gina Milgate *(ACER)*	***Challenges and Opportunities for Neuroscience: How to explain the connection between sociocultural practices and cognition*** Professor David Clarke *(The University of Melbourne)* & Dr Hilary Hollingsworth *(ACER)* Chair: Dr Jenny Bryce *(ACER)*	***The Benefits of Music for the Brain*** Professor Sarah Wilson *(The University of Melbourne)* Chair: Dr Elizabeth Hartnell-Young *(ACER)*

12.00 – 1.00 Lunch

1.00 – 2.15 Plenary 4 – Understanding Learning: Lessons for learning, teaching and research
Professor John Hattie *(The University of Melbourne)*
Chair: Dr Siek Toon Khoo *(ACER)*

2.15 – 3.00 Futuregazing
Dr Paul Howard-Jones; Ms Barbara Arrowsmith-Young; Dr Bruno della Chiesa; Professor Martin Westwell
Chair: Mr Adam Smith *(ACER Board)*

3.00 **Closing Address –** Professor Geoff Masters, CEO, ACER

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Our teacher resources include Building Comprehension Strategies, by Dr Alison Davis and Belair on Display. *TeachersMatter* magazine is another great resource for teachers on our lists. We also are involved in PD sessions throughout the year.

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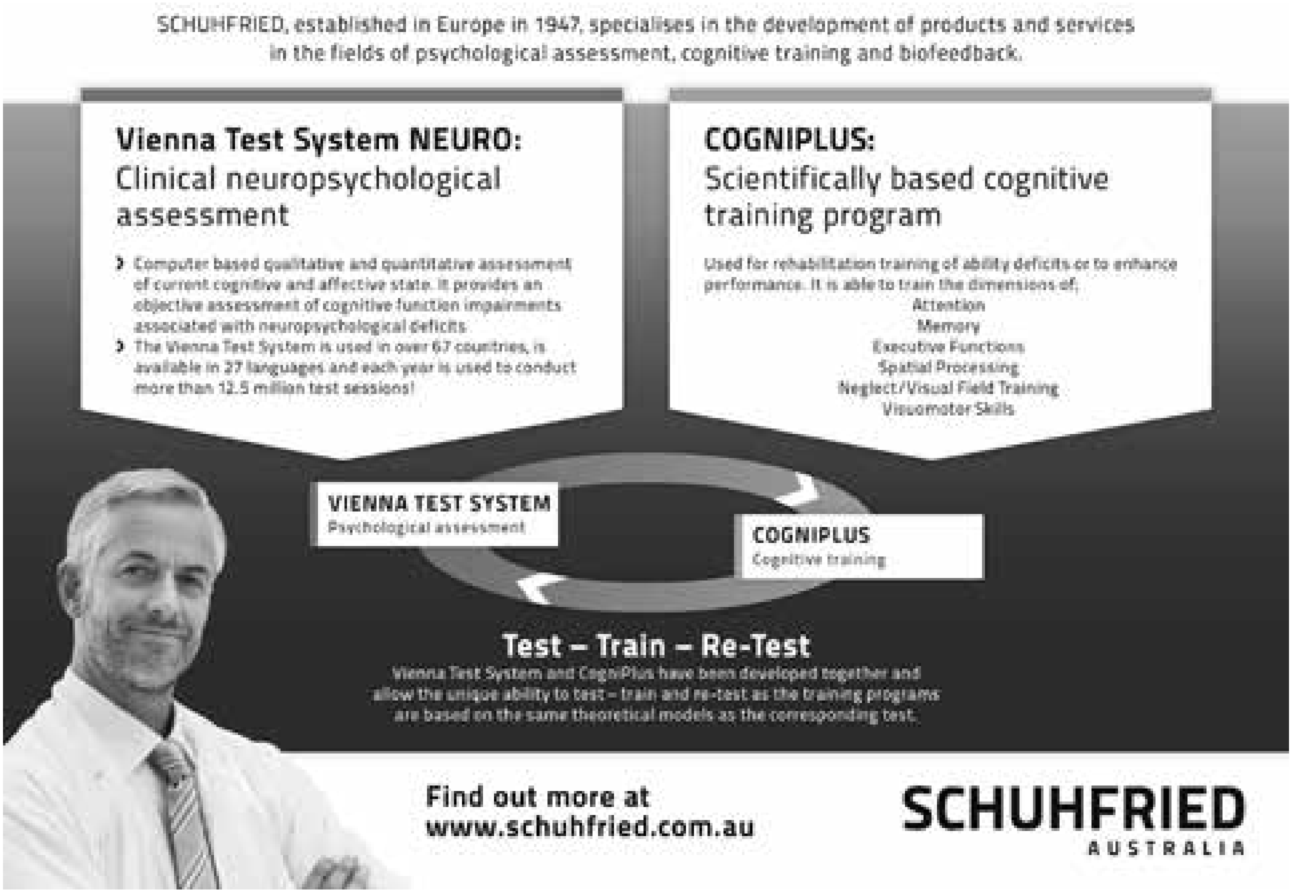

SCHUHFRIED

Schuhfried, established in Europe in 1947, specialises in the development of computerised psychological assessment and cognitive rehabilitation and training tools. Schuhfried Australia was established in 2012 as a fully independent company with a head office in Brisbane. Schuhfried products have been used in the industrial and HR field in Australia for over 15 years through partner company Veedre.

Schuhfried has three integrated product lines:

- Vienna Test System (VTS) is used in psychometric assessment of human abilities and attributes
- The CogniPlus program is used in rehabilitation training of ability deficits or to enhance performance
- Biofeedback is used to train people to control physical factors like pulse and heart rate and thereby control anxiety, attention, thinking and emotions.

The VTS comprises four versions in the application areas of Neuro, HR, Traffic (rail, road, air) and Sport. Each of these systems includes a dimensions list and test directory specifically tailored to the particular field of use. They also contain a number of test sets – combinations of test dimensions useful for exploring particular complex issues. In total, there are over 100 tests in the VTS, including computerised versions of many familiar paper and pencil tests. VTS is used in over 67 countries and is available in 27 languages. Each year, VTS is used to conduct 12.5 million test sessions.

CogniPlus is a computerised system for training cognitive functions. It is closely linked to the VTS allowing users the unique ability to test – train – retest. CogniPlus is able to train the dimensions of Attention, Neglect/Visual field training, Memory, Executive functions, Spatial processing and Visuo-motor skills.

AUSTRAINING INTERNATIONAL

FROM THE MALDIVES TO MONGOLIA, AUSTRALIAN EDUCATOR MAKES A DIFFERENCE

Education professional James Anthony has been sharing his skills and experience with communities in developing countries by implementing education initiatives in the Maldives, and now Mongolia.

As an Australian Volunteer for International Development in the Maldives, James was based on an atoll (a group of islands) where he assisted with teacher training and developing resources. The Maldives is made up of a collection of many atolls, which creates difficulties in delivering professional development across the education sector.

Recognising this challenge, James developed 'whole country' staff training through a tool called Moodle, an online course management system that allows teachers to put their classes online.

'I feel confident that I left behind a system that has been embraced with enthusiasm, and know that the knowledge that I have imparted is having a positive, sustainable impact on education for the Maldivians', James says.

'The experience of volunteering in that idyllic setting of the Maldives made an impact on me. I was welcomed into families and cared for as though I was one of their own.'

James is now part-way through his second Australian Volunteers assignment with the Ministry of Education and Science as an English Language Specialist. His main focus is on training teachers in modern teaching methodologies, developing resource materials appropriate to Mongolia and improving the teachers' English proficiency.

'Just as in the Maldives, I want to be able to help make a difference.'

Australian Volunteers assignments are now available in countries throughout Asia, the Pacific, Africa, Latin America and the Caribbean.

To register your interest in the Australian Volunteers program and receive updates and information, visit http://www.volunteering.austraining.com.au/volunteer-with-us/register

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Miss Tobey Abbott	*Teacher*	Trinity Anglican School, QLD
Ms Susan Abigail	*Senior Guidance Officer*	Education Queensland
Mr Peter Adams	*General Manager*	ACARA, NSW
Ms Anne Addicoat		CEO Sydney, NSW
Miss Samantha Adler	*Occupational Therapist*	
Mr Luke Ahrens	*Psychologist*	Beechworth Psychology, VIC
Dr John Ainley	*Principal Research Fellow*	ACER
Mrs Lyn Alder	*Research Fellow*	Simerr National Centre One, NSW
Ms Denise Alexander	*Special Education*	Leibler Yavneh College, VIC
Mrs Maryclare Alison		
Ms Katherine Alling	*Teacher*	Corrective Services, NSW
Mrs Kerstin Andersson	*Learning Support Coordinator*	Mt Barker Waldorf School, SA
Ms Manuela Andrew	*Teacher*	Katherine School of the Air, NT
Ms Dale Anthony	*Head Teacher Curriculum*	PLC, NSW
Ms Jan Archer	*Teacher of Mathematics*	Lesmurdie Senior High School, WA
Ms Alison Arnott	*Psychology/Indigenous Educ. Teacher*	Kormilda College, NT
Ms Barbara Arrowsmith-Young	*Director*	Arrowsmith School
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Mrs Carol Barnett		Launceston Christian School, TAS

Name	Position	Organisation
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Ms Ricky Campbell-Allen	*Director, Centre for New Public Education*	Foundation for Young Australians, VIC
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Ms Neila Darrough	*K–12 Mathematics Education Officer*	Catholic Education Office, NSW
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Ms Janelle DeBois		
Dr John DeCourcy	*Director*	Catholic Education Office, NSW
Mr Murray Deeps	*Principal*	Holy Family School, NSW
Dr Bruno della Chiesa	*Visiting Lecturer*	Harvard University

Name	Position	Organisation
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Ms Susan Dennett	*Manager*	DEECD, VIC
Dr Sacha DeVelle	*Manager and Principal Research Fellow*	ACER
Mr Lance Deveson		ACER
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Mr Grahame Dickson	*Head of School – Canberra*	AIE, NSW
Mr Jackson Dodd	*Deputy Principal*	Aldridge State High School, QLD
Miss Clare Donnan	*Teacher*	Lowther Hall Anglican Grammar, VIC
Mr Steven Dover	*Director, Human Resources*	ACER
Mrs Margaret Downey	*Teacher*	Sarah Redfern High School, NSW
Mrs Helen Doyle	*Project Officer*	SiMEER, University of New England, NSW
Mr Patrick Doyle		San Clemente High School, NSW
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Mrs Amanda Eastman	*Assistant to Director of Studies*	Barker College, NSW
Mr Tim Edmonds	*Head of Curriculum*	Pembroke School, SA
Mrs Jennifer Edstein-Byes	*Principal*	St Joseph's Charlestown, NSW
Mrs Sally Egan	*Director of Improvement Strategy*	Pymble Ladies' College, NSW
Mr David Ella	*Education Officer*	Catholic Schools Office, NSW
Ms Shirley Ellis	*Partnership Mentor*	DEC, NSW
Mrs Jacqui Ellison	*Curriculum Coordinator*	Plenty Valley Christian College, VIC
Ms Karen Endicott	*Principal*	Sarah Redfern High School, NSW
Mrs Sandra Erickson	*Assistant Principal*	Glen Waverley Secondary College, VIC
Ms Dana Eriksen	*Teacher*	Petrie Terrace State School, QLD
Mrs Raelene Ernst	*Learning Support Teacher*	Canberra Girls Grammar School, ACT
Mr Bill Esman	*Chemistry Teacher*	Padua College, VIC
Ms Sheri Evans	*Deputy Principal*	Medina Primary School, WA
Mrs Rose Famiano	*Teacher in Charge of Languages*	Lesmurdie Senior High School, WA
Mr Chris Fanning	*Assistant Principal*	St Mary's Warners Bay, NSW
Dr Adelle Faull	*Quality Teaching Learning Coordinator*	Avondale School, NSW

Name	Position	Organisation
Dr David Faull	*Principal*	Avondale School, NSW
Miss Keira Favale	*Teacher*	Burdekin Catholic High School, QLD
Mr Brian Featherton	*Assistant Regional Director*	DECD, SA
Mr Dominic Fecteau	*Teacher*	OLSH Thamarrur Catholic College, NT
Mr David Fetterplace	*Principal*	All Saints Catholic Senior College, NSW
Mrs Lyn Fetterplace	*Leader of Pedagogy*	Freeman Catholic College, NSW
Ms Robyn Field	*SEO2 Quality Teaching Consultant*	Dept. of Education & Communities, NSW
Ms Jillian Finch	*Assistant Principal*	Nightcliff Primary School, NT
Associate Professor Cordelia Fine	*ARC Future Fellow*	The University of Melbourne, VIC
Mrs Megan Finnigan	*Teacher*	Marist College, ACT
Mrs Janis Fischer	*Principal*	Rosanna Golf Links Primary School, VIC
Mrs Clare Fletcher	*Coordinator*	St Mary MacKillop College, ACT
Mrs Ruth Fletcher	*Resource Teacher*	Te Akau ki Papamoa School, NZ
Mrs Shirley Fletcher	*Assistant Principal*	Hallam Primary School, VIC
Miss Karen Flood	*Director of Support Services*	Woodleigh School, VIC
Ms Catherine Ford	*Assistant Principal*	Wantirna College, VIC
Mr Tom Forrest	*Teacher*	Sacred Heart College, VIC
Ms Marijke Fortia	*Partnerships Coordinator*	Austraining International, SA
Mr Brett Foster	*Education Sales Consultant*	ACER
Ms Rowena Fox	*Regional Director*	DECD, SA
Mr Brendan Fraser	*Dean of Middle Years*	Xavier College – Burke Hall, VIC
Ms Jen Fraser	*Director*	Eye Can Spell, QLD
Miss Tiali Fraser	*Director of Teaching and Learning*	Arden Anglican School, NSW
Mr James Friend	*Teacher*	Shore School, NSW
Ms Kelly Fullarton	*Senior Psychologist*	DSF Literacy & Clinical Services, WA
Mrs Cathryn Furey	*Assistant Principal*	Ruyton Girls' School, VIC
Mrs Elka Gaensler	*Head of Primary – General Studies*	Leibler Yauneh College, VIC
Miss Priscilla Gaff	*Program Coordinator, Life Sciences*	Melbourne Museum, VIC
Mrs Danielle Gagliardi	*Senior Leader*	Seaford 6–12 School, SA
Mrs Tosca Galluzzo	*Teacher Educator*	Our Lady of the Rosary, NSW
Ms Siobhan Galos	*Coordinator Years 2–7, L & T*	Catholic Education Office, WA

Name	Position	Organisation
Mrs Emma Gates	*Teacher*	Ivanhoe Girls' Grammar School, VIC
Ms Kelli Gibbs	*Head of Learning/Teaching*	St Peter's Primary School, VIC
Ms Susan Gilheany	*Liaison Principal*	DEECD, Regional Office, VIC
Mrs Debbie Gilmore	*Australia/NZ Contact*	Arrowsmith Program, NSW
Mrs Trish Gleeson	*Education Officer*	Catholic Schools Office, NSW
Mrs Sara Gold	*Speech and Language Therapist*	Inspire 2 Learn, VIC
Mrs Anne Goodfellow	*Teacher*	Rona Glynn Preschool, NT
Ms Vicki Goodsell	*School Counsellor*	Catholic Education Office, QLD
Professor Peter Goodyear	*Professor of Education*	University of Sydney, NSW
Mr Ron Gorman	*Deputy Director*	AIS, WA
Mr Max Grarock		Teaching Learning Network, VIC
Mr Robert Gratton	*Principal*	Mandurah Baptist College Primary, WA
Ms Elizabeth Gray	*Senior Guidance Officer*	Education Queensland
Mrs Geraldine Gray	*State Coordinator*	CEC, NSW
Mr John Greene	*Education Consultant*	Rosebank College, NSW
Mrs Brooke Griffith	*Support Teacher*	Logan Village State School, QLD
Mrs Peta Guy		
Ms Sarah Guy	*Head of Junior School*	St Catherine's School, NSW
Ms Natalie Hagan	*Postgraduate & Nursing Research Coordinator*	Alfred Health, VIC
Mrs Sue Hage	*Teacher*	Seaford Rise Primary School, SA
Ms Shona Hall	*Dean of Teaching & Learning*	Perth College, WA
Ms Carolyn Hamilton		Catholic College, Bendigo, VIC
Mrs Cheryl Hamilton	*Principal*	Loreto College, QLD
Miss Kerryn Hancock		St Paul's School, QLD
Mr Peter Harold	*Studies Coordinator*	All Saints College, NSW
Ms Jackie Harris	*Assistant Principal*	Norwood Secondary College, VIC
Mrs Cheryl Harrison	*Director of Education Support*	Scotch College Junior School, VIC
Miss Narelle Harry	*LT Team Leader*	Northern Bay College, VIC
Dr Elizabeth Hartnell-Young	*Director*	ACER
Ms Leonie Harwood	*Coordinator*	Immanuel College, SA
Mr Robert Hassell	*Coordinator*	AIS, WA

Name	Position	Organisation
Professor John Hattie	*Director*	The University of Melbourne, VIC
Mrs Wendy Hawking	*Teacher & Learning Coordinator*	Yarra Valley Grammar, VIC
Mr Damian Hawkins	*General Manager*	Fiber & Copper Inc., NSW
Ms Tracy Healy	*Head of Senior School*	Lowther Hall Anglican Grammar, VIC
Mrs Mary Height	*Educational Clinician*	Kingsley Professional Centre, WA
Mrs Julie Heincke	*School Assistant – Special Needs*	Canberra Girls Grammar School, ACT
Mrs Sandra Hewson	*Assistant Principal*	Kildare College, SA
Mrs Janice Heyworth	*Principal*	St Fiacre's Catholic Primary School, NSW
Mr Jason Higgins	*Teacher*	Ascham School, NSW
Mrs Kim Higgs	*Special Education Teacher*	Cittaway Bay Primary School, NSW
Mr David Hill	*Teacher*	OLSH Thamarrur Catholic College, NT
Mr Sean Hill	*Principal*	Stella Maris Parish School, SA
Ms Jenny Holland	*Principal*	Lurnea High School, NSW
Dr Hilary Hollingsworth	*Senior Research Fellow*	ACER
Miss Tracy Holmes	*Principal*	Mandurah Baptist College, WA
Ms Jillian Holmes-Smith	*Director*	SREAMS, VIC
Mr Philip Holmes-Smith	*Director*	SREAMS, VIC
Mr David Holzworth	*Director*	Schuhfried Australia, QLD
Mr Michael Hopkinson	*School Leadership Consultant*	Catholic Schools Office, NSW
Dr Samantha Hornery	*Manager – Educational Support*	Learning Links, NSW
Ms Gaye Hoskins	*Secondary Curriculum Consultant*	DEC, NSW
Mr Daniel Hough	*Leading Teacher*	Mansfield Secondary College, VIC
Dr Paul Howard-Jones	*Senior Lecturer*	University of Bristol, UK
Mr David Huggins	*Assistant Director*	Catholic Education Office, VIC
Ms Carol Hughes	*Director*	Lioncrest Education, NSW
Mrs Ann Hunt	*Teacher*	St Joseph's Primary School, NSW
Mr Anthony Hunter	*Education Consultant*	Catholic Schools Office, NSW
Mrs Leonie Ince	*Head of Intervention*	Ballarat Clarendon College, VIC
Ms Jo Inglis	*Head of Learning & Teaching*	The Southport School, QLD
Ms Julia Inglis	*Education Sales Consultant*	ACER Press, VIC
Mrs Anne Ingram	*Dean of Students*	Brisbane Girls Grammar School, QLD

Name	Position	Organisation
Ms Kay Ishak	*Director*	Alphabeta Group, NSW
Ms Melinda Italiano	*Assist. Dean Teaching & Learning*	Penrhos College, WA
Mrs Samantha Jackson	*SeO2, Prof Learning*	DEC, NSW
Ms Sue Jackson	*Assistant Principal*	East Bentleigh Primary School, VIC
Ms Mary Jacquier	*Principal*	St Ann's Special School, SA
Ms Stefa Jarema	*Director of Student Services*	Bacchus Marsh Grammar, VIC
Mrs Annemaree Johnsen	*Teacher*	St Peter's Anglican College, NSW
Mr Gary Johnson	*Principal*	Cherrybrook Technology High School, NSW
Mrs Sophie Johnson	*Teacher – Education Support*	Scotch College Junior School, VIC
Ms Wendy Johnstone	*Senior Pathways Coordinator*	Presentation College, VIC
Ms Polly Jones	*Classroom Teacher*	Lajamanu, VIC
Mrs Linden Jones-Drzyzga	*Principal*	St Mary's Warners Bay, NSW
Mr Michael Juliff	*Principal*	St Peter's Primary School, VIC
Mr Christopher Kay	*Assistant Principal*	Donvale Christian College, VIC
Mrs Fiona Kearnan	*Director of Curriculum*	Plenty Valley Christian College, VIC
Mr Tim Kelly	*Deputy Headmaster*	Toowoomba Grammar School, QLD
Ms Gabrielle Kempton	*Head of Learning*	St Paul's School, QLD
Mr Allan Kennedy	*Teacher*	Avila College, VIC
Mrs Joanne Kenny	*Middle Leader*	St Paul's Primary School, NSW
Dr Siek Toon Khoo	*Research Director, Psychometrics and Methodology*	ACER
Ms Tina King	*Principal*	Watsonia North Primary School, VIC
Dr Julie Kos		ACER
Ms Carmel Kostos		Next Talent Development, VIC
Ms Carmel Kriz	*Team leader – Curriculum Teaching & Learning*	Catholic Schools Office, NSW
Mrs Jillian Kube	*Leading Teacher*	Nhill College, VIC
Mr John Kural	*Manager, Education Regulation*	DES, WA
Ms Wilma Kurvink	*College Head of Libraries*	Wesley College, VIC
Miss Anne Lam	*Centre Psychologist*	Juvenile Justice, NSW
Miss Jennifer Lamet	*Director of Studies*	Kennedy Baptist College, WA
Mrs Adele Langdale	*Deputy Principal*	Hercules Road State School, QLD

Name	Position	Organisation
Mr Peter Langfield	*HT Mentor*	Rooty Hill High School, NSW
Ms Janelle Larkin	*Curriculum Leader*	Berry Street School, VIC
Mr Jai Law	*Leading Teacher*	Warragul Regional College, VIC
Mr Andrew Lawrence	*Year 7 Coordinator*	Yarra Valley Grammar, VIC
Mr Brian Laybutt	*Principal*	Mt St Patrick Primary School, NSW
Ms Penelope Layton-Caisely	*Director*	Walking-Talking-English School, NSW
Mrs Jan Leather	*Director of Teaching and Learning*	Ivanhoe Girls' Grammar School, VIC
Dr Kevin Lee	*Principal*	Murray Bridge North School, SA
Mrs Rachael Lehr	*HOD Science*	West Beechboro Primary School, WA
Ms Elisabeth Lenders	*Principal*	Kingswood College, VIC
Mr Edward Leonard		San Clemente High School, NSW
Mrs Helen Leyendekkers	*Teacher – Special Needs*	Bunbury Catholic College, WA
Mr Joshua Lickiss	*Policy Officer*	DEEWR, ACT
Mrs Jillian Lienert	*Minister*	Uniting Church, SA
Ms Li-Ai Lim	*Product Manager*	ACER Press, VIC
Ms Emma Lindsay	*Curriculum Manager*	Sarah Redfern High School, NSW
Professor Ottmar Lipp	*Deputy Director*	University of Queensland
Dr Debora Lipson	*Lecturer – Science Education*	Victoria University, VIC
Ms Jenny Little	*Deputy Principal*	Korowa Anglican Girls' School, VIC
Mrs Kathryn Little	*RFF*	St Joseph's Narrandera, NSW
Ms Donna Livermore	*Learning Engagement Manager*	Zoos Victoria
Ms Sheryl Livingstone	*Senior Guidance Officer*	DETE, QLD
Mrs Amanda Lobegeiger	*Head of Mathematics & Science*	Carmel Adventist College, WA
Dr Jason Lodge	*Lecturer*	Griffith University
Mr Stephen Loggie	*Executive Principal*	Palm Beach Currumbin State High, QLD
Mr Jason Loke	*Senior Leader, STEM Learning*	Australian Science and Maths School, SA
Mrs Bernadette Long	*Maths Leader*	St Carlo Borromeo, VIC
Mrs Kate Long	*Learning Enhancement Teacher*	Somerville House, QLD
Dr Lye Chan Long	*Gifted Education Mentor*	O.L.M.C., NSW
Ms Jessica Lopez		San Clemente High School, NSW
Mr Brian Loughland	*Assistant Principal*	Brigidine College, St Ives, NSW

Name	Position	Organisation
Mrs Cathryn Louwen	*Year 3/4 Teacher*	Tweed Valley Adventist College, NSW
Ms Sue Low	*Principal*	Chatswood High School, NSW
Mrs Cordillia Lowe	*Teachers Aide*	Northside Christian College, VIC
Mrs Kylie Lowe	*Head Teacher*	Lurnea High School, NSW
Dr Tom Lumley	*Senior Research Fellow*	ACER
Ms Therese Lunghusen	*Middle Years Curriculum Coordinator*	Xavier College – Kostka Hall, VIC
Ms Jacqueline Lyons	*Principal*	Sydney Technical High School, NSW
Mr Tony MacDonald	*Psychologist*	Catholic Education Office, VIC
Mrs Julie MacFarlane	*Principal*	Hallam Primary School, VIC
Ms Lucy Macken	*English/Psychology Teacher*	Kambala, NSW
Mrs Anne Madden	*General Manager*	Pearson Clinical & Talent Assessment, NSW
Mrs Sheree Maksoud	*Deputy Principal*	Logan Village State School, QLD
Ms Petr Malapanis	*Learning and Development Coordinator*	NWT, VIC
Mr Michael Maniska	*Principal*	International Grammar School, NSW
Mrs Maura Manning	*Director of Teaching and Learning*	Pymble Ladies' College, NSW
Mr Jonathan Maranik	*Classroom Teacher*	Lurnea High School, NSW
Ms Milena Maranville	*Principal*	Ivanhoe East Primary School, VIC
Mrs Anne Marceau	*Senior Advisor, Teaching and Learning*	DEC, NSW
Mrs Anne-Marie Marias	*Research Student*	Charles Darwin University, NT
Mr Robert Marshall	*Senior Project Director*	ACER
Miss Cathy Martin	*Educational Psychologist*	Melbourne Girls Grammar School, VIC
Ms Jenny Mason	*Assistant Principal*	Norwood Secondary College, VIC
Professor Geoff Masters	*CEO*	ACER
Mr Greg Mattiske	*Deputy Principal*	Suncoast Christian College, QLD
Mr Jonathon Mayall	*Teacher*	Shore School, NSW
Mr Kevin Maynes	*Director*	Genesis Institute Pty Ltd, VIC
Ms Rose McAllister		San Clemente High School, NSW
Mr Adam McCann	*Teacher*	St Joseph's Taree, NSW
Mrs Anette McCann		Catholic Education Office, NSW
Dr Paul McCann	*Head of School Services*	Catholic Education Office, NSW
Mrs Kym McCarthy	*Dean of Educational Assessment*	Sunshine Coast Grammar School, QLD

Name	Position	Organisation
Mrs Jan McClure	*Deputy Principal*	Ballarat Clarendon College, VIC
Ms Jo-Anne McDonagh	*Assistant Principal*	St Ann's Special School, SA
Mr Ken McDonald	*Counsellor*	St Paul's School, QLD
Mr Mark McDonald	*Principal*	St Francis Xavier Primary, NSW
Mr Michael McDonald	*College Deputy*	Mt Alvernia College, QLD
Mrs Margie McDonough	*Special Education Teacher*	Scotch College Junior School, VIC
Mrs Jennifer McGie	*Head of English/Literacy*	Ballarat Clarendon College, VIC
Mrs Loretta McGill	*Education Officer*	Catholic Education Office, QLD
Mr Andrew McGregor		Westbourne Grammar School, VIC
Mr Peter McGuckian	*Director of International Development*	ACER
Ms Kay McInenney	*Deputy Principal*	Murray Bridge North School, SA
Mrs Charmaine McKee	*Learning Support Coordinator*	Star of the Sea College, VIC
Mr James McKee	*Deputy Principal*	Aldridge State High School, QLD
Mrs Kerry McKee	*Literacy Leader*	St Peter's Primary School, VIC
Hon Maxine McKew	*Vice Chancellors' Fellow*	The University of Melbourne, VIC
Ms Sarah McKillup	*Teacher*	
Ms Jillian McLaren	*Teacher*	Penleigh & Essendon Grammar, VIC
Ms Jennifer McLean	*Head of Learning Enrichment*	Kambala, NSW
Mrs Brooke McNamara	*Senior Project Officer*	DEECD, VIC
Mrs Allyson Mead	*Kindergarten Director*	Meningie Kindergarten, SA
Mrs Linda Meeks	*Director*	Ants in the Apple Pty Ltd, NSW
Mrs Melanie Meers	*Principal Education Officer*	DEC, NSW
Mrs Stephanie Meggitt	*Science Teacher*	All Hallows' School, QLD
Assoc. Prof. Jeff Mehring		Ohkagakuen University, JAPAN
Ms Marion Meiers	*Senior Research Fellow*	ACER
Mr Nick Melaisis		Catholic College, Bendigo, VIC
Ms Beatrice Melita	*Psychologist*	Private Practice, VIC
Mrs Elizabeth Mellor	*Director*	The Awakening Network, VIC
Mr Paul Menday	*Director*	Catholic Education Office, NSW
Ms Hayley Merat	*Teacher*	Kingsville Primary School, VIC
Dr Antonio Mercurio	*Executive Manager, Curriculum Services*	SACE Board of South Australia, SA

Name	Position	Organisation
Dr Bradley Merrick	*Director of Research in Learning*	Barker College, NSW
Mrs Lea Michael	*Head of School – Online*	AIE, NSW
Mr Peter Michael	*Assistant Principal*	St Paul's Primary School, NSW
Mrs Monique Miers	*Classroom Teacher*	Mayfield State School, QLD
Ms Gina Milgate	*Indigenous Liaison Officer*	ACER
Mr Paul Milgate	*Leader of Pedagogy*	Xavier Catholic College, NSW
Ms Martina Millard	*Deputy Principal – Junior School*	Sacred Heart College, VIC
Mr Daniel Miller	*Head of Department*	AIE, NSW
Mr Glen Miller	*Principal*	Erasmus School, VIC
Mrs Virginia Milliken	*Education Officer*	Catholic Schools Office, NSW
Mrs Monique Miotto	*Head of Learning*	Erasmus School, VIC
Miss Silvia Montoya	*Directora General De Evaluation*	GCBA, ARGENTINA
Mrs Cathryn Moore	*Curriculum Coordinator*	Ascham School, NSW
Ms Jacqueline Moore	*Research Fellow*	ACER
Ms Jo Moore	*Principal*	Travancore School, VIC
Mrs Jillian Morgan	*Head of Mission & Education Services*	Catholic Education Office, TAS
Miss Julia Morris	*Research Student*	Edith Cowan University, WA
Mrs Kelly Morrow	*Assistant Principal*	Rosanna Golf Links Primary School, VIC
Ms Gayle Morton	*Deputy Principal*	Aspley Special School, QLD
Mrs Gaye Moses	*Teacher*	Swan Hills Education, WA
Mr Michael Mullaly	*Education Consultant*	Catholic Schools Office, NSW
Dr Rose Mulraney	*Senior Manager*	RMIT University, VIC
Ms Pamela Mulready	*Learning Designer*	The Learning Architect, VIC
Associate Professor John Munro	*Head of Studies*	The University of Melbourne, VIC
Mr Robert Muscat	*Principal*	St Clare's Catholic High School, NSW
Associate Professor Michael Nagel		University of the Sunshine Coast, QLD
Ms Danielle Najm	*Clincial Practice Manager*	Alfred Health, VIC
Mrs Tricia Neate	*Principal*	Elanora State School, QLD
Ms Sonia Nelson	*Assistant Principal*	Kildare College, SA
Mr Mark Newhouse	*Manager of Curriculum*	AISWA, WA
Mrs Lyn Newman	*Learning Support Teacher*	Mosman Prep, NSW

Name	Position	Organisation
Ms Thanh Nguyen	*Teacher*	Korowa Anglican Girls' School, VIC
Mrs Marie Nilon	*Principal*	Our Lady of the Rosary Primary, NSW
Ms Susan Nilsen	*Snr Education Officer*	Berry Street School, VIC
Miss Lauren Nisbett	*Teacher, Dance, The Arts*	Lesmurdie Senior High School, WA
Ms Donna Nitschke	*Coordinator*	Neuroscience in the Classroom, SA
Ms Annie Nolan	*Education Officer: Early Years*	Catholic Education Office, TAS
Ms Kathryn Nolan	*Project Officer*	Catholic Education Office, VIC
Mrs Lorraine Northey	*Resource Teacher Learning & Behaviour*	Te Akau ki Papamoa School, NZ
Ms Rosalie Nott	*Assistant Director, Policy*	Catholic Education Commission, NSW
Ms Jo Nowak	*Senior Psychologist*	School Psychology Services, WA
Ms Maria O'Donnell	*Teaching/Learning Coordinator*	St Mary MacKillop College, ACT
Mrs Kara Oliver	*Partnership Broker*	AusSIP, NSW
Mrs Priscilla O'Mahoney	*Teacher*	St Joseph's Primary School, NSW
Mr Francis O'Mara	*Teacher*	Downlands College, QLD
Mr Tim O'Neill	*Teacher*	St Mary's High School, NSW
Mr Stevon Orlando	*Head of Secondary*	Meadowbank Education, NSW
Ms Rita Osborne	*School Counsellor*	Catholic Education Office, NSW
Mrs Helen O'Toole	*Principal*	St Jerome's Primary School, WA
Mrs Jo Paini	*School Support Consultant*	Catholic Education Office, WA
Miss Annamaria Paolino	*Student*	Edith Cowan University, WA
Ms Katerina Papapetros	*Teacher*	Seymour College, SA
Dr Sofia Pardo	*Lead Researcher*	ideasLAB, VIC
Ms Katherine Parker	*Manager, Curriculum Learning Areas*	DEECD, VIC
Dr Pauline Parker	*T & L Advisor*	Lasseter Group School, NT
Mrs Sherry Parker	*Coordinator*	Curtin PEAC, WA
Mr Paul Parlison	*Teacher*	Noosa Pengari Steiner School, QLD
Ms Mary-Ellen Pattinson	*Education Consultant*	Catholic Education Office, QLD
Ms Cath Pearn	*Teaching Fellow*	ACER
Dr Douglas Peck	*Principal*	Plenty Valley Christian College, VIC
Professor John Pegg	*Professor and Foundation Director*	University of New England, NSW
Ms Yvonne Peros	*Cogmed Training & Support Manager*	Pearson Clinical & Talent Assessment, NSW

Name	Position	Organisation
Ms Deborah Perz	*Teacher*	Brisbane Girls Grammar School, QLD
Mr Andrew Pesle	*Deputy Principal*	Rooty Hill High School, NSW
Ms Beth Phelan	*Conference Director*	World Happiness Forum, NSW
Mrs Tanya Phillips	*Teacher*	Wollongong Conservatorium of Music, NSW
Mrs Susan Phipps	*Year 3–4 Coordinator*	Plenty Valley Christian College, VIC
Ms Anne Pillman	*PhD Student*	Flinders University, SA
Mrs Sue Plumb	*Head of Art, Design & Technology*	Yarra Valley Grammar, VIC
Miss Donna Plumridge	*Deputy Principal*	Liverpool Girls High School, NSW
Mrs Lynne Pokela	*Head of Junior School*	Good Shepherd Lutheran College, NT
Mr Nicholas Pole	*Deputy Secretary*	DEECD, VIC
Ms Angela Pollicino	*Science Teacher*	Saint Ignatius College, NSW
Ms Isabella Pozzolungo	*Head Teacher*	St Clair's High School, NSW
Ms Leonie Praetz	*Principal*	Nhill College, VIC
Mrs Allison Prandolini	*Head of Junior School*	Lowther Hall Anglican Grammar, VIC
Mr Robert Prest	*Director of Curriculum*	Woodcroft College, SA
Mr Matt Priest		San Clemente High School, NSW
Dr Jenny Proimos	*Principal Medical Advisor*	DEECD, VICbridges Consulting Pty Ltd, VIC
Ms Sheridan Pruteanu		San Clemente High School, NSW
Ms Tracey Puckeridge	*CEO*	Steiner Education Australia, NSW
Mrs Lynne Pull	*Principal*	St Anthony's School, NSW
Ms Tony Pullella	*Head of Primary School*	St Mark's Anglican Comm. School
Mrs Yianna Pullen	*Assistant Principal*	Wooranna Park Primary School, VIC
Mr Brendan Pye	*Project Director*	ACER
Professor Bridie Raban	*Professional Research Fellow*	The University of Melbourne, VIC
Mr Jeremy Rackham	*Teacher*	The Friends' School, TAS
Ms Dara Ramalingam	*Senior Research Fellow*	ACER
Mr Scott Ramsdell	*Psychologist*	Beechworth Psychology, VIC
Ms Therese Rasch	*Teacher*	Petrie Terrace State School, QLD
Mr Hugh Rasmusen	*Regional Equity Coordinator WNSWR*	DEC, NSW
Mrs Glenys Rathjen	*Teacher*	Bundaberg Christian College, QLD
Mr Ian Rathjen	*Teacher*	Bundaberg Christian College, QLD

Name	Position	Organisation
Dr David Rawnsley	*Director of Curriculum*	St John's Grammar School, SA
Mrs Tonja Raymond	*Special Education Teacher*	Peninsula Teaching and Tutoring, VIC
Mr Max Rayner	*L & D Coordinator*	A & C Training & Development, SA
Mrs Sally Rayner	*Senior School Psychologist*	Learning Services (N-W), TAS
Mrs Vanessa Rebgetz	*Deputy Principal*	Queensland Academy for Health Sciences, QLD
Ms Eve Recht		Educational Writer & Consultant
Dr Kate Reid	*Research Fellow*	ACER
Mr Adam Rekrut	*Secondary Teacher*	Holy Cross College, NSW
Mrs Victoria Rennie	*Deputy Headmistress*	St Catherine's School, NSW
Ms Elisabeth Rhodes	*Principal*	Lowther Hall Anglican Grammar, VIC
Mr Daniel Richardson	*Middle School Coordinator*	Moonta Area School, SA
Dr Sarah Richardson	*Senior Research Fellow*	ACER
Ms Elizabeth Riley	*School Adviser*	Catholic Education Office, VIC
Ms Ann Roberts	*DP Learning & Teaching*	Marist Regional College, TAS
Ms Elizabeth Roberts	*Principal Consultant*	Department of Education, WA
Mr James Roberts	*Head of Campus – Cranbourne East*	St Peter's College, VIC
Mrs Melinda Roberts	*Faculty Head of Arts*	Xavier College, VIC
Ms RitaMay Roberts	*Speech Pathologist*	
Mrs Karen Robertson	*Principal*	St Catherine's Primary School, VIC
Mr Geoff Roberts-Thomson	*Deputy Principal*	Oxley Christian College, VIC
Ms Mel Robinson	*Acting Religious Education Coordinator*	St Joseph's Taree, NSW
Mrs Valerie Robinson	*Psychologist*	DEECD, VIC
Ms Julie Rolfe	*Student Wellbeing Officer*	Catholic Education Office, NSW
Ms Lynda Rosman	*Manager*	ACER
Dr Sam Rothman	*Principal Research Fellow*	ACER
Mrs Merylyn Rowe	*Teacher*	Loxton Primary School, SA
Mrs Sheena Ruedas	*Special Education Consultant*	Catholic Education, SA
Mr Rob Ruediger	*Year 11 Coordinator*	Immanuel College, SA
Mr David Russell	*School Coordinator*	St Alban's Secondary College, VIC
Ms Gillian Rutherford		San Clemente High School, NSW

Name	Position	Organisation
Mrs Jennifer Rutherford	*Education Officer*	Brisbane Catholic College, QLD
Mr Robert Ruzbacky	*Daily Organiser*	St Aloysius College, VIC
Ms Anne Ryan	*Support Teacher*	St Columba's, Wilston, QLD
Mrs Carolyn Ryan	*Leading and Support Teacher*	Dorrigo High School, NSW
Dr Erica Ryan	*Education Office – Gifted/High Achievers*	Catholic Schools Office, NSW
Mr James Ryan	*Training Manager*	Pathways to Resilience Trust, QLD
Mrs Sophie Ryan		Catholic Education Office, NSW
Mrs Dulcie Ryman	*Middle Leader*	St Paul's Primary School, NSW
Professor Pankaj Sah	*Deputy Director*	University of Queensland
Mr Stephen Said	*Senior Coordinator Student Wellbeing*	Catholic Education Office, NSW
Miss Ana Sala-Oviedo	*Director, Educational Planning*	New Learning Environments, SA
Mr Carl Salt	*Head of Junior School*	Pembroke School, SA
Mr Laurie Sammut		St Joseph's School, SA
Mr James Samphier	*Deputy Principal*	Lurnea High School, NSW
Mr Mark Sampson	*Head of Senior School*	Wesley College, WA
Mr Ben Sanders	*Community Conservation Officer*	Zoos Victoria
Mrs Mary Sapio	*Individual Needs*	Immaculate Heart of Mary, SA
Mr Ralph Saubern	*Director, Professional Services*	ACER
Mr Nick Saunders	*Head of Preparatory School*	Shore Preparatory School, NSW
Mrs Chris Sawrey	*Learning Enrichment Coordinator*	Sunshine Coast Grammar School, QLD
Ms Lauren Sayer	*Head of Teaching and Learning*	Royal Children's Hospital, VIC
Ms Agnes Scherrenberg	*Special Education Teacher*	Caulfield Grammar School, VIC
Mrs Megan Scholz	*Head of Individual Programs*	Yarra Valley Grammar, VIC
Ms Sue Schouten	*Policy Officer*	DEEWR, ACT
Ms Sandra Scott	*School Psychologist*	DEC, NSWbridges Consulting Pty Ltd, VIC
Mr Malina Scout	*General Manager*	Fiber & Copper Inc., NSW
Mr Nigel Scozzi	*Head of Department Geography*	Shore School, NSW
Mrs Marie Seaford	*Team Leader – Special Needs*	Catholic Schools Office, NSW
Mr Phil Shannon	*Deputy Principal*	St Bernard's College, VIC
Mrs Gabrielle Sheahan	*School Adviser*	Catholic Education Office, VIC
Mrs Maria Shearn	*Principal*	East Bentleigh Primary School, VIC

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Ms Caroline Sheehan	*Director of Teaching and Learning*	Xavier College, VIC
Mr David Sheil	*Director, Teaching & Learning*	St Dominic's College, NSW
Mr David Shepherd	*Principal*	Ballarat Clarendon College, VIC
Mrs Joy Short	*Director*	Catholic Education Office, NSW
Mr Grant Siermas	*Teacher*	OLSH Thamarrur Catholic College, NT
Mrs Sue Sifa	*Principal*	Raukkan Aboriginal School, SA
Mrs Yvette Sims	*Pathway Coordinator/Teacher*	Tenison Woods College, SA
Ms Kirsten Slape		DEECD, VIC
Mrs Jane Sleeman	*Principal*	Queensland Academy for Health Sciences, QLD
Mr Morris Sleep	*Consultant*	DEECD, VIC
Mr James Sloman	*Principal*	Mansfield State High School, QLD
Ms Amanda Smith	*Principal*	Holy Rosary Primary School, VIC
Mrs Anita Smith	*Snr Education Officer*	Brisbane Catholic Education, QLD
Ms Barbara Smith	*School Program Manager*	ACER
Mrs Danielle Smith	*Educational Support Teacher*	St Catherine's School, VIC
Ms Kristin Smith	*Project Officer*	Flinders Centre for Science Educ. in the 21st Century, SA
Mrs Nadine Smith	*Deaf Facility Coordinator*	Rosanna Golf Links Primary School, VIC
Mr Vaughan Smith	*Head of Research and Development*	Caulfield Grammar School, VIC
Mrs Vicky Smith	*Teacher*	
Mr Christopher Smyth	*Secondary Consultant*	Catholic Schools Office, NSW
Mr Darren Smyth	*Head of Mathematics*	Ivanhoe Grammar School, VIC
Ms Emma South		San Clemente High School, NSW
Ms Gabriella Spadaro	*Learning Support Specialist*	Marymount International School, ITALY
Mr Kevin Sparks	*Director of Teaching and Learning*	Prince Alfred College, SA
Mrs Karen Spiller	*Principal*	St Aidan's Anglican Girls' School, QLD
Miss Bridie Stanger	*Teacher*	St Joseph's Taree, NSW
Ms Skye Staude	*Teacher*	Berry Street School, VIC
Ms Annie Sterck	*Head of Middle School*	Korowa Anglican Girls' School, VIC
Ms Juanita Steym	*Preparatory Teacher*	Whitsunday Anglican School, QLD

Name	Position	Organisation
Mrs Bente Stock	*Principal*	Whittlesea Primary School, VIC
Ms Emily Stocker	*Student*	UNE, NSW
Dr Andy Stone	*Senior Leader, Interdisciplinary Science*	Australian Science and Maths School, SA
Ms Rosa Storelli	*Adjunct Professor*	La Trobe University, VIC
Mrs Zannah Stredwick	*Coordinator, Learning Enrichment*	Ravenswood School for Girls, NSW
Ms Elizabeth Suda	*Program Coordinator, Humanities*	Melbourne Museum, VIC
Ms Jeanette Sullivan	*Coordinator, Learning Support Programs*	St Mary's College, TAS
Ms Christina Surmei	*PhD Candidate*	University of Adelaide, SA
Mrs Pauline Swain		Ivanhoe Grammar School, VIC
Mrs Amanda Swaney	*Consultant*	Sandhurst NE Catholic Schools, VIC
Mr Ray Swann	*T/L Coordinator*	Yarra Valley Grammar, VIC
Ms Donna Sweeney	*Deputy Principal*	St Paul's Anglican School, VIC
Mrs Helen Tachas	*Chemistry Teacher, Senior School*	Carey Baptist Grammar School, VIC
Dr Barbara Tadich	*Coach, Teaching and Learning*	Bendigo South East College, VIC
Ms Carmel Tapley	*Education Officer*	Maitland Newcastle CSO, NSW
Dr Pina Tarricone	*Postdoctoral Research Fellow*	Edith Cowan University, WA
Ms Narelle Tasker	*Clinical Nurse/Consultant*	St George Hospital, NSW
Ms Charmaine Taylor	*Director – Curriculum Services*	VCAA, VIC
Ms Margaret Taylor	*Administrative Officer*	ACER
Mr Alwyn Terpstra	*Principal*	John Calvin Christian College, WA
Mr Christopher Thompson	*A/Executive Director*	DEECD, VIC
Mrs Ingrid Thompson	*Head of Religious Education*	Brigidine College, St Ives, NSW
Ms Rhonda Thompson		Catholic Education Offfice, Sydney, NSW
Mr Luke Thomson	*Principal*	Pembroke School, SA
Dr Sue Thomson	*Head of Educational Monitoring and Research; Research Director, National Surveys Research Program*	ACER
Ms Bernadette Thorne	*Partner*	Effective Teaching, NSW
Mrs Amanda Tighe	*Speech Pathologist*	Brisbane Catholic College, QLD
Dr Mike Timms	*Director*	ACER
Prof Helen Timperley		University of Auckland, NZ

Name	Position	Organisation
Dr Stephen Tobias	*Head of School*	University of New England, NSW
Mrs Fay Tran	*Literacy Consultant*	
Mrs Christina Trimble	*Principal*	Marist Sisters' College, NSW
Mrs Joanne Trotter	*Principal*	St Joseph's Primary School, NSW
Mr David Trousdell	*Year 9 Coordinator*	Seymour College, SA
Mr David Turner	*Principal*	Bald Hills State School, QLD
Ms Glenda Tyler		Haileybury, VIC
Mrs Bronwyn Underwood	*Principal*	St Joseph's Primary School, NSW
Ms Susan Upton	*Leading Teacher*	St Arnaud Secondary College, VIC
Dr Elvira Vacirca	*Manager*	DEECD, VIC
Mr Geoff van der Vliet	*Deputy Principal*	Nambour Christian College, QLD
Ms Lynette Van Zeeland		San Clemente High School, NSW
Mrs Wendy Veitch	*Teaching & Learning Leader*	Rosanna Golf Links Primary School, VIC
Mr James Victor	*Teacher (Secondary)*	Camberwell Grammar School, VIC
Mr Michael Victory	*Executive Officer*	Teaching Learning Network, VIC
Ms Anne-Marie Vine	*Principal*	Kariong Mountains High School, NSW
Mrs Jennie Vine	*Assistant Principal*	Wooranna Park Primary School, VIC
Mr Vin Virtue	*Principal*	Norwood Secondary College, VIC
Mr Mark Vodell	*Principal*	Gilson College, VIC
Mrs Margaret Vrdoljak	*Learning Enrichment Coordinator*	O.L.M.C., NSW
Mr Brendan Waddy	*Deputy Principal*	Mandurah Baptist College Primary, WA
Mrs Emma-Lee Walker	*Teacher/Coordinator*	GSLPS, VIC
Mrs Julia Walker	*Teaching & Learning Suppoort*	Plenty Valley Christian College, VIC
Ms Julie Walker	*Mathematics Coordinator*	Loreto Kirribilli, NSW
Mrs Sue Walsh	*Director System Learning*	Catholic Education Office, Parramatta, NSW
Mrs Christine Walsh-Hipwell	*Teacher*	Eastbourne Primary School, VIC
Ms Ann Walton	*Research Fellow*	Simerr National Centre One, NSW
Ms Susan Warming	*Manager, Ed Support Services*	Berry Street Education, VIC
Mrs Vicki Waters	*Principal*	Pymble Ladies' College, NSW
Mrs Katherine Watkinson	*Private Educational Consultant*	
Mrs Connie Watson	*Principal*	North Fitzroy Primary School, VIC

Name	Position	Organisation
Mrs Donna-Maree Watt	*Teacher*	St Joseph's Primary School, NSW
Mr John Watters	*Executive Officer*	AusSIP, NSW
Mrs Jenny Weal	*Deputy Principal*	Cherrybrook Technology High School, NSW
Mrs Elizabeth Webster	*RE Coordinator*	Loreto College, NSW
Ms Cathy Welsford	*Partner*	Effective Teaching, NSW
Mrs Jennifer Werakso	*Principal*	St Brigid's Catholic School, NSW
Mr Howard West	*Assistant Principal Secondary*	Aust. International School, Hong Kong
Mrs Karen Westacott	*Teacher*	
Professor Martin Westwell	*Strategic Professor in the Science of Learning*	Flinders University, SA
Dr Dan White	*Executive Director*	Catholic Education Office, Sydney, NSW
Mrs Rosalee Whiteley	*Literacy Consultant 9–12*	DEC, NSW
Mrs Juliana Whiteman	*Board of Studies Coordinator*	Ravenswood School for Girls, NSW
Mrs Vicki Whittaker	*Principal*	St James Primary School, NSW
Ms Ann Williams	*Student*	Deakin University, VIC
Mrs Debra Williams	*English Teacher*	Saint Ignatius College, NSW
Mrs Monica Williams	*Principal*	Meningie Area School, SA
Mrs Susanne Williams	*Consultant*	Catholic Education, WA
Mr Keiran Williamson		San Clemente High School, NSW
Dr John Willison	*Senior Lecturer*	School of Education, Univ. of Adelaide, SA
Ms Lisa Wills	*SACE Officer*	SACE Board of South Australia, SA
Mrs Amanda Wilson	*Principal*	Holy Spirit College, NSW
Ms Amy Wilson	*Teacher*	John Hunter Hospital School, NSW
Mr John Wilson	*Principal*	St Finbarr's Primary School, NSW
Professor Sarah Wilson		The University of Melbourne, VIC
Ms Therese Wilson	*Deputy Principal – Learning & Teaching*	Santa Maria College, VIC
Ms Trina Wilson		Catholic College, Bendigo, VIC
Mr Christopher Witt	*Consultant*	AIS, WA
Dr Andrew Wood	*Education Officer – Student Wellbeing*	Brisbane Catholic Education, QLD
Ms Claire Wood	*Psychologist*	Ad Altona Psychology, NSW
Mr David Wood	*Chief Learning, Teaching & Innov. Officer*	Catholic Education Office, WA
Mrs Christine Woods	*Head of Drama*	Loreto College, NSW

Name	Position	Organisation
Dr Geoff Woolcott	*Senior Lecturer*	Southern Cross University, NSW
Dr Tony Yeigh	*Lecturer/Research Associate*	Southern Cross University, NSW
Mrs Jennifer York	*Quality Teaching Consultant*	DEC, NSW
Dr Anne-Marie Youlden	*Director, Educational & Child Psychologist*	Educare Specialist Services, NSW
Mr Alexander Young	*CEO*	Ingenious Technological Enterprises, TAS

As of Friday 19 July 2013