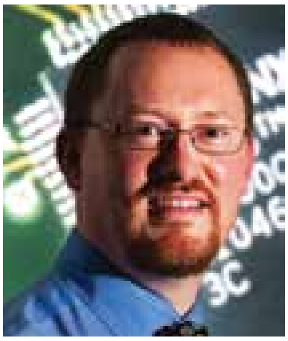
WHEN THE EDUCATIONAL NEUROSCIENCE MEETS THE AUSTRALIAN CURRICULUM: A STRATEGIC APPROACH TO TEACHING AND LEARNING



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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).

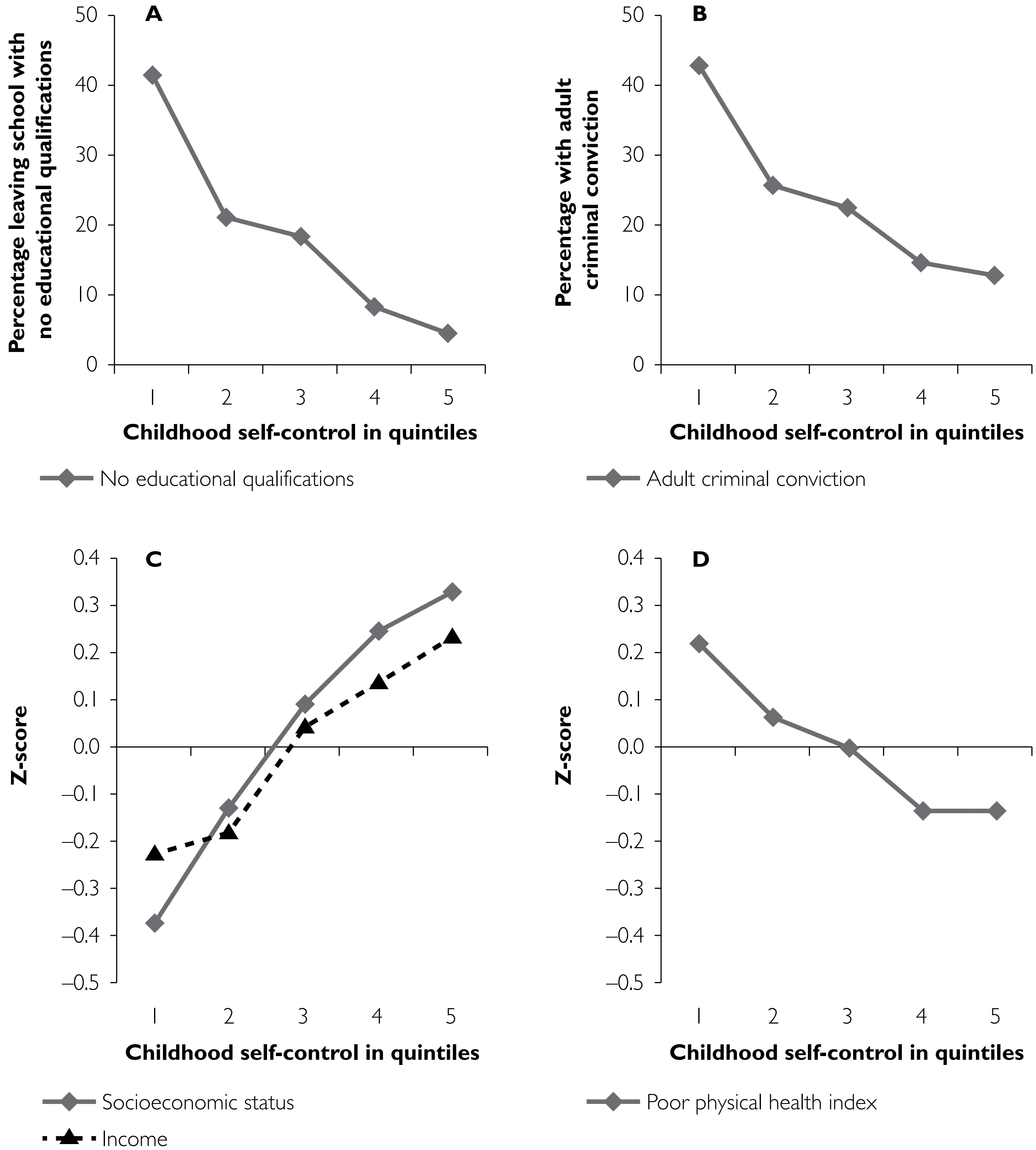

Figure 1 Impact of childhood self-control on outcomes in adulthood

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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