

## Executive Summary

Education is like a double-edged sword. It may be turned to dangerous uses if it is not properly handled.

Wu Ting-Fang

**A**fter two decades of pioneering work in brain research, the education community has started to realise that “understanding the brain” can help to open new pathways to improve educational research, policies and practice. This report synthesises progress on the brain-informed approach to learning, and uses this to address key issues for the education community. It offers no glib solutions nor does it claim that brain-based learning is a panacea. It *does* provide an objective assessment of the current state of the research at the intersection of cognitive neuroscience and learning, and maps research and policy implications for the next decade.

Part I “The Learning Brain” is the main report, which is the distillation from all the analyses and events over the past seven years of the OECD/CERI “Learning Sciences and Brain Research” project. Part II “Collaborative Articles” contains three articles devoted to the “learning brain” in early childhood, adolescence and adulthood, respectively. These have been written, in each case, by three experts who have combined their experience and knowledge in synergy of the different perspectives of neuroscience and education. Annex A reproduces some insights and dialogue that have emerged from the project’s interactive website, open to civil society and including notably a teachers’ forum. Annex B updates the reader with developments in neuroimaging technology which have proved so fundamental to the advances discussed in this report.

The first chapter offers a novel “ABC” of the contents of the report by listing and discussing keywords in alphabetical order. This serves both to give short summaries of complex concepts and to steer the reader towards the relevant chapter(s) providing the more in-depth coverage. This is followed in the first half of the following chapter by a short but essential overview of the brain’s architecture and functioning.

---

### *How the brain learns throughout life*

---

Neuroscientists have well established that the brain has a highly robust and well-developed capacity to change in response to environmental demands, a process called *plasticity*. This involves creating and strengthening some neuronal connections and weakening or eliminating others. The degree of modification depends on the *type* of learning that takes place, with long-term learning leading to more profound modification. It also depends on the *period* of learning, with infants experiencing extraordinary growth of new synapses. But a profound message is that plasticity is a core feature of the brain throughout life.

There are optimal or “sensitive periods” during which particular types of learning are most effective, despite this lifetime plasticity. For sensory stimuli such as speech sounds, and for certain emotional and cognitive experiences such as language exposure, there are relatively tight and early sensitive periods. Other skills, such as vocabulary acquisition, do not pass through tight sensitive periods and can be learned equally well at any time over the lifespan.

Neuroimaging of adolescents now shows us that the adolescent brain is far from mature, and undergoes extensive structural changes well past puberty. Adolescence is an extremely important period in terms of emotional development partly due to a surge of hormones in the brain; the still under-developed pre-frontal cortex among teenagers may be one explanation for their unstable behaviour. We have captured this combination of emotional immaturity and high cognitive potential in the phrase “high horsepower, poor steering”.

In older adults, fluency or experience with a task can reduce brain activity levels – in one sense this is greater processing efficiency. But the brain also declines the more we stop using it and with age. Studies have shown that learning can be an effective way to counteract the reduced functioning of the brain: the more there are opportunities for older and elderly people to continue learning (whether through adult education, work or social activities), the higher the chances of deferring the onset or delaying the acceleration of neurodegenerative diseases.

---

### *The importance of environment*

---

Findings from brain research indicate how nurturing is crucial to the learning process, and are beginning to provide indication of appropriate learning environments. Many of the environmental factors conducive to improved brain functioning are everyday matters – the quality of social environment and interactions, nutrition, physical exercise, and sleep – which may seem too obvious and so easily overlooked in their impact on education. By conditioning our minds and bodies correctly, it is possible to take advantage of the brain’s potential for plasticity and to facilitate the learning process. This calls for holistic approaches which recognise the close interdependence of physical and intellectual well-being and the close interplay of the emotional and cognitive.

In the centre of the brain is the set of structures known as the limbic system, historically called the “emotional brain”. Evidence is now accumulating that our emotions do re-sculpt neural tissue. In situations of excessive stress or intense fear, social judgment and cognitive performance suffer through compromise to the neural processes of emotional regulation. Some stress is essential to meet challenges and can lead to better cognition and learning, but beyond a certain level it has the opposite effect. Concerning positive emotions, one of most powerful triggers that motivates people to learn is the illumination that comes with the grasp of new concepts – the brain responds very well to this. A primary goal of early education should be to ensure that children have this experience of “enlightenment” as early as possible and become aware of just how pleasurable learning can be.

Managing one’s emotions is one of the key skills of being an effective learner; self-regulation is one of the most important behavioural and emotional skills that children and older people need in their social environments. Emotions direct (or disrupt) psychological processes, such as the ability to focus attention, solve problems, and support relationships. Neuroscience, drawing on cognitive psychology and child development research, starts to identify critical brain regions whose activity and development are directly related to self-control.

---

### Language, literacy and the brain

---

The brain is biologically primed to acquire language right from the very start of life; the process of language acquisition needs the catalyst of experience. There is an inverse relationship between age and the effectiveness of learning many aspects of language – in general, the younger the age of exposure, the more successful the learning – and neuroscience has started to identify how the brain processes language differently among young children compared with more mature people. This understanding is relevant to education policies especially regarding foreign language instruction which often does not begin until adolescence. Adolescents and adults, of course, can also learn a language anew, but it presents greater difficulties.

The dual importance in the brain of sounds (phonetics) and of the direct processing of meaning (semantics) can inform the classic debate in teaching reading between the development of specific phonetic skills, sometimes referred to as “syllabic instruction”, and “whole language” text immersion. Understanding how both processes are at work argues for a balanced approach to literacy instruction that may target more phonetics or more “whole language” learning, depending on the morphology of the language concerned.

Much of the brain circuitry involved in reading is shared across languages but there are some differences, where specific aspects of a language call on distinct functions, such as different decoding or word recognition strategies. Within alphabetical languages, the main difference discussed in this report is the importance of the “depth” of a language’s orthography: a “deep” language (which maps sounds onto letters with a wide range of variability) such as English or French contrasts with “shallow”, much more “consistent” languages such as Finnish or Turkish. In these cases, particular brain structures get brought into play to support aspects of reading which are distinctive to these particular languages.

Dyslexia is widespread and occurs across cultural and socioeconomic boundaries. Atypical cortical features which have been localised in the left hemisphere in regions to the rear of the brain are commonly associated with dyslexia, which results in impairment in processing the sound elements of language. While the *linguistic* consequences of these difficulties are relatively minor (e.g. confusing words which sound alike), the impairment can be much more significant for *literacy* as mapping phonetic sounds to orthographic symbols is the crux of reading in alphabetic languages. Neuroscience is opening new avenues of identification and intervention.

---

### Numeracy and the brain

---

Numeracy, like literacy, is created in the brain through the synergy of biology and experience. Just as certain brain structures are designed through evolution for language, there are analogous structures for the quantitative sense. And, also as with language, genetically-defined brain structures alone cannot support mathematics as they need to be co-ordinated with those supplementary neural circuits not specifically destined for this task but shaped by experience to do so. Hence, the important role of education – whether in schools, at home, or in play; and hence, the valuable role for neuroscience in helping address this educational challenge.

Although the neuroscientific research on numeracy is still in its infancy, the field has already made significant progress in the past decade. It shows that even very simple numerical operations are distributed in different parts of the brain and require the co-ordination of

multiple structures. The mere representation of numbers involves a complex circuit that brings together sense of magnitude, and visual and verbal representations. Calculation calls on other complex distributed networks, varying according to the operation in question: subtraction is critically dependent on the inferior parietal circuit, while addition and multiplication engage yet others. Research on advanced mathematics is currently sparse, but it seems that it calls on at least partially distinct circuitry.

Understanding the underlying developmental pathways to mathematics from a brain perspective can help shape the design of teaching strategies. Different instructional methods lead to the creation of neural pathways that vary in effectiveness: drill learning, for instance, develops neural pathways that are less effective than those developed through strategy learning. Support is growing from neuroscience for teaching strategies which involve learning in rich detail rather than the identification of correct/incorrect responses. This is broadly consistent with formative assessment.

Though the neural underpinnings of dyscalculia – the numerical equivalent of dyslexia – are still under-researched, the discovery of biological characteristics associated with specific mathematics impairments suggests that mathematics is far from a purely cultural construction: it requires the full functioning and integrity of specific brain structures. It is likely that the deficient neural circuitry underlying dyscalculia can be addressed through targeted intervention because of the “plasticity” – the flexibility – of the neural circuitries involved in mathematics.

---

### Dispelling “neuromyths”

---

Over the past few years, there has been a growing number of misconceptions circulating about the brain – “neuromyths”. They are relevant to education as many have been developed as ideas about, or approaches to, how we learn. These misconceptions often have their origins in some element of sound science, which makes identifying and refuting them the more difficult. As they are incomplete, extrapolated beyond the evidence, or plain false, they need to be dispelled in order to prevent education running into a series of dead-ends.

Each “myth” or set of myths is discussed in terms of how they have emerged into popular discourse, and of why they are not sustained by neuroscientific evidence. They are grouped as follows:

- “There is no time to lose as everything important about the brain is decided by the age of three.”
- “There are critical periods when certain matters *must* be taught and learnt.”
- “But I read somewhere that we only use 10% of our brain anyway.”
- “I’m a ‘left-brain’, she’s a ‘right-brain’ person.”
- “Let’s face it – men and boys just have different brains from women and girls.”
- “A young child’s brain can only manage to learn one language at a time.”
- “Improve your memory!”
- “Learn while you sleep!”

---

### *The ethics and organisation of educational neuroscience*

---

The importance and promise of this new field are not the reason to duck fundamental ethical questions which now arise.

*For which purposes and for whom?* It is already important to re-think the use and possible abuse of brain imaging. How to ensure, for example, that the medical information it gives is kept confidential, and not handed over to commercial organisations or indeed educational institutions? The more accurately that brain imaging allows the identification of specific, formerly “hidden”, aspects of individuals, the more it needs to be asked how this should be used in education.

*The use of products affecting the brain:* The boundary between medical and non-medical use is not always clear, and questions arise especially about healthy individuals consuming substances that affect the brain. Should parents, for instance, have the right to give their children substances to stimulate their scholarly achievements, with inherent risks and parallels to doping in sport?

*Brain meets machine:* Advances are constantly being made in combining living organs with technology. The advantages of such developments are obvious for those with disabilities who are thus enabled, say, to control machines from a distance. That the same technology could be applied to control individuals’ behaviour equally obviously raises profound concerns.

*An overly scientific approach to education?* Neurosciences can importantly inform education but if, say, “good” teachers were to be identified by verifying their impact on students’ brains, this would be an entirely different scenario. It is one which runs the risk of creating an education system which is excessively scientific and highly conformist.

Though educational neuroscience is still in its early days, it will develop strategically if it is trans-disciplinary, serving both the scientific and educational communities, and international in reach. Creating a common lexicon is one critical step; another is establishing shared methodology. A reciprocal relationship should be established between educational practice and research on learning which is analogous to the relationship between medicine and biology, co-creating and sustaining a continuous, bi-directional flow to support brain-informed educational practice.

A number of institutions, networks and initiatives have already been established to show the way ahead. Vignette descriptions of several leading examples are available in this report. They include the JST-RISTEX, Japan Science and Technology’s Research Institute of Science and Technology for Society; Transfer Centre for Neuroscience and Learning, Ulm, Germany; Learning Lab, Denmark; Centre for Neuroscience in Education: University of Cambridge, United Kingdom; and “Mind, Brain, and Education”, Harvard Graduate School of Education, United States.

---

### *Key messages and themes for the future*

---

*Educational neuroscience is generating valuable new knowledge to inform educational policy and practice:* On many questions, neuroscience builds on the conclusions of existing knowledge and everyday observation but its important contribution is in enabling the move from correlation to causation – understanding the mechanisms behind familiar patterns – to help identify effective solutions. On other questions, neuroscience is generating new knowledge, thereby opening up new avenues.

*Brain research provides important neuroscientific evidence to support the broad aim of lifelong learning:* Far from supporting ageist notions that education is the province only of the young – the powerful learning capacity of young people notwithstanding – neuroscience confirms that learning is a lifelong activity and that the more it continues the more effective it is.

*Neuroscience buttresses support for education’s wider benefits, especially for ageing populations:* Neuroscience provides powerful additional arguments on the “wider benefits” of education (beyond the purely economic that counts so highly in policy-making) as it is identifying learning interventions as a valuable part of the strategy to address the enormous and costly problems of ageing dementia in our societies.

*The need for holistic approaches based on the interdependence of body and mind, the emotional and the cognitive:* Far from the focus on the brain reinforcing an exclusively cognitive, performance-driven bias, it suggests the need for holistic approaches which recognise the close inter-dependence of physical and intellectual well-being, and the close interplay of the emotional and cognitive, the analytical and the creative arts.

*Understanding adolescence – high horsepower, poor steering:* The insights on adolescence are especially important as this is when so much takes place in an individual’s educational career, with long-lasting consequences. At this time, young people have well-developed cognitive capacity (high horsepower) but emotional immaturity (poor steering). This cannot imply that important choices should simply be delayed until adulthood, but it does suggest that these choices should not definitively close doors.

*Better informing the curriculum and education’s phases and levels with neuroscientific insights:* The message is a nuanced one: there are no “critical periods” when learning *must* take place but there are “sensitive periods” when the individual is particularly primed to engage in specific learning activities (language learning is discussed in detail). The report’s message of an early strong foundation for lifetimes of learning reinforces the key role of early childhood education and basic schooling.

*Ensuring neuroscience’s contribution to major learning challenges, including the “3Ds”: dyslexia, dyscalculia, and dementia.* On dyslexia, for instance, its causes were unknown until recently. Now it is understood to result primarily from atypical features of the auditory cortex (and possibly, in some cases, of the visual cortex) and it is possible to identify these features at a very young age. Early interventions are usually more successful than later interventions, but both are possible.

*More personalised assessment to improve learning, not to select and exclude:* Neuroimaging potentially offers a powerful additional mechanism on which to identify individuals learning characteristics and base personalisation; but, at the same time, it may also lead to even more powerful devices for selection and exclusion than are currently available.

Key areas are identified as priorities for further educational neuroscientific research, not as an exhaustive agenda but as deriving directly from the report. This agenda for further research – covering the better scientific understanding of such matters as the optimal timing for different forms of learning, emotional development and regulation, how specific materials and environments shape learning, and the continued analysis of language and mathematics in the brain – would, if realised, be well on the way to the birth to a trans-disciplinary learning science.

This is the aspiration which concludes this report and gives it its title. It is also the report’s aspiration that it will be possible to harness the burgeoning knowledge on learning to create an educational system that is both personalised to the individual and universally relevant to all.