Educating the brain

The growing knowledge about how our brain works can inform educational programmes and approaches, in particular, for children with learning problems

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British science fiction author H.G. Wells wrote that, “Human history becomes more and more a race between education and catastrophe,” in *The Outline of History*. This maxim remains as true as ever. Access to education is not only a human right, it is the foundation of a successful and productive society, and it is even crucial for the future of our planet. Numeracy and literacy are skills that are required in almost every profession; humanity needs to research and develop new technologies to cope with famine, diseases, environmental degradation and energy production—all of which require highly qualified people. Education is our most important resource.

Given the importance of education, it is not surprising that the growing field of educational neuroscience is attracting considerable interest. After all, neuroscience is the science of the brain and one of the major features of the brain is its ability to learn. It is hoped that, as we expand our knowledge of the brain and how it learns, we can apply this insight to improving classroom education. Indeed, recent decades have seen a massive increase in brain research, and the rapid development of functional imaging techniques has created unprecedented possibilities for observing the brain in action.

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The idea that neuroscience research might provide guidance for teachers sounds promising. However, as with any new and

aspiring research field, educational neuroscience has suffered to some extent from over-optimism and wishful thinking. A huge demand for improving educational practice has been a fertile ground for misconceptions around the question of how neuroscience can be applied to education. Speculative educational applications have emerged in the name of neuroscience [1,2].

In 2002, the Brain and Learning project of the Organization for Economic Cooperation and Development (OECD) published a book *Understanding the Brain: Towards a New Learning Science*, in which they drew attention to this phenomenon and coined the term ‘neuromythologies’ [3]. In 2012, Sanne Dekker and colleagues from the LEARN! Institute at the VU University in Amsterdam, the Netherlands, and Bristol University in the UK, evaluated the prevalence of neuromyths among teachers in selected regions in the United Kingdom and the Netherlands. More than 80% of the teachers surveyed agreed with statements such as the following: “Individuals learn better when they receive information in their preferred learning style (for example, auditory, visual, kinesthetic)”; “Differences in hemispheric dominance (left brain, right brain) can help explain individual differences among learners”; and “Short bouts of coordination exercises can improve integration of left and right hemispheric brain function” [4]. Other neuromyths suppose that there are critical periods in childhood after which certain things can no longer be learned, or that stimuli-rich environments improve the brains of preschool children. Moreover, Dekker and her colleagues found that knowledge about the brain does not protect against neuromyths. Teachers who

knew more about the brain were more likely to believe the myths.

Many neuromyths are based on actual scientific findings, but have distorted or misunderstood the message. For example, the myth that people are either ‘left-brain’ or ‘right-brain’ thinkers can be traced back to several studies on hemispheric differences [3,5] and studies of ‘split-brain’ patients. These patients suffered from severe epilepsy, and in the 1960s the only treatment was to sever the *corpus callosum*, which connects the left and right cerebral hemispheres. This allowed researchers to study the function of the brain hemispheres independently. For example, split-brain patients could only name objects if they were presented in a way that the left hemisphere of the brain could process them. On the other hand, they seemed more versatile in spatial tasks when the right hemisphere was engaged.

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These and other studies have led to the belief that the left hemisphere is the seat of language and rational thinking, whereas the right hemisphere is responsible for intuition, emotion and non-verbal and synthetic thinking that is required for spatial tasks. This is an over-simplification, as the two hemispheres of the brain work together in all cognitive tasks. Nonetheless, the widespread belief in hemisphericity has spawned questionable educational practices, including the

claim that most educational programmes are designed to educate predominantly the left hemisphere, and that this should be counter-balanced by activities that teach the right hemisphere specifically [3].

Other mythologies are similarly based on the misinterpretation of valid scientific results. The fact that fledglings have a critical period during which they imprint on their parents does not entail that the time window for learning certain tasks closes forever at a given age in humans. The observation that rats perform better in a maze learning test when they are kept in enriched environments cannot be extrapolated to children and classrooms [3].

The list of conclusions that cannot be drawn from neuroscience is long, but this does not preclude that neuroscience can contribute to education. There are promising approaches to unravelling brain functions that are directly relevant to school education, and considerable progress has been made in understanding the neurocognitive underpinning of essential

skills such as reading and calculating. In these areas, neuroscience and cognitive psychology have teamed up to elucidate the learning process and are paving the way towards classroom application.

Specific neuronal systems, most notably in the parietal region, are activated whenever adults calculate or compare numbers. Within this region, the horizontal segment of the bilateral intraparietal sulcus is sometimes the only area specifically activated in simple number comparison or number detection tests, suggesting that it has a central role in the basic representation of numerical quantity [6]. Moreover, the intraparietal areas involved in numerosity are close to or even overlapping with areas engaged in handling physical dimensions such as size, location, angle and luminance [7,8]. This tight correlation seems to be more than a coincidence, as the link between number processing and location in space is of functional relevance. Even from early developmental stages, humans use spatial representation of numbers, which is referred to as the 'mental number line', usually assigning left space

to small numbers and right space to large numbers [7,8]. Whenever we are confronted with numbers, this spatial representation is automatically accessed, as shown in several behavioural experiments. For example, in a simple test in which participants were asked to judge whether numbers were odd or even, they responded faster to small numbers when they pressed a response key with their left hand, whereas responses to larger numbers were faster when using their right hand. "Evidence for the number line can be detected in almost every human being, but most people are not aware of it," said Hans-Christoph Nürk, Professor of Psychology at the University of Tübingen, Germany, who works on how to apply this knowledge in education.

Indeed, this spatial representation seems to help us whenever we deal with numbers. In 2008, Julie Booth and Robert Siegler from Carnegie Mellon University in the USA found a functional association between the spatial representation of numbers and arithmetic development [9]. A better number line in children was predictive of their ability to

tackle unfamiliar arithmetical problems. It is possible that this concept can be exploited in mathematical education. Studies show that children who practice their mental number line in board games [10], or in games that involve physical activity, such as moving along a traced number line [11], also improve in numerical competence.

Space is a prominent association that is intuitively activated during number processing, but it is not the only one. The human homologue of the anterior intraparietal area, which is involved in the coordination of hand movements, lies in close proximity to the horizontal segment of the bilateral intraparietal sulcus [7,8]. Again, this does not seem to be a coincidence. Almost all children use their fingers when they learn to count and calculate. At least to some extent, this carries on into adulthood. “Imagine you book a holiday from December 28 to January 3. How many nights is that?” Nürk asked. “You will probably use your fingers to find out.” Several studies have shown that the anterior intraparietal area is activated during number processing [8,12], and that the fact that we have five fingers on each hand even has an impact on calculation strategies—we tend to divide numbers into portions of five to handle them more easily. For example, adults are slower when calculating problems that cross the boundary of five (for example, four plus three) than solving problems that do not cross this boundary (for example, five plus two; [13]).

“In many didactic books, it is suggested that children’s habit to use their fingers when counting should be ceased as soon as possible,” Nürk said. Neuroscience has called this belief into question. In fact, there are even indications that using fingers to count might be preferable—a notion that Nürk is investigating in more detail. For example, studies have shown that children with good finger gnosis in first grade, are also better at mathematics later in their development [14]. If the brain has its own strategies for handling numbers—space and fingers—why not make use of them when teaching maths? “Ideas from didactics may be traced back to Jean Piaget, according to whom there is a concrete operational stage that later needs to be replaced by an abstract formal-operational stage. Our idea is rather that we retain what we have learned previously and that our cognition builds on that,” Nürk explained.

Mathematics education has been hotly discussed between scientists, policy-makers, teachers and parents. Such societal debates were often triggered by political events [15] such as the launch of the satellite Sputnik by the Soviets or the 1980s economic crisis. The term ‘math wars’ has been coined to describe some of the more recent turmoil in the USA [15]. Is mathematics for the elite or for the masses? Are there tensions between ‘excellence’ and ‘equity’? Neuroscience surely cannot answer these questions, but it does have something to say about mathematical education—not so much about what to teach, but rather about how to teach.

As seen with the ‘math wars’, reading has had its wars too throughout the twentieth century [16]. Two teaching methods were promoted and contrasted—‘phonics-based’ reading and ‘whole language’ reading. Phonics teaches children how to convert the visual patterns of print into the sound of spoken language, whereas the whole language method, which gained influence in the 1930s and ‘40s, claims that reading is a natural process that unfolds effortlessly once children are exposed to printed matter, just as children learn to speak if they are exposed to spoken language. Thus, the whole language method puts emphasis on the meaning of the words, rather than the tools needed to decipher the text itself. Several large-scale educational studies conducted throughout the 1960s and 1980s eventually resolved the issue. It is widely accepted that direct instruction of how to convert orthography into phonology—sounding out letters and strings of letters—is an essential part of learning to read, although some emphasis on meaning is also helpful. It is difficult to understand in retrospect why opinions in the debate were so polarized and why the reading wars were fought so fiercely. One reason might be that literacy is of such considerable importance to our society.

Although the debate is resolved, neuroscience has provided an explanation for the answer and some ideas to refine the teaching of reading. Neuroimaging studies have uncovered several interrelated neuronal systems specifically involved in reading [17–19]; most importantly, systems in the left occipito-temporal and parieto-temporal regions. The left parieto-temporal system is crucial for word analysis, and it is involved in mapping the visual input

of print onto the related phonological structure of language. This system is particularly active in young children who are learning to read, indicating that translating print into phonological sound is a key early reading strategy. The left occipito-temporal system contains the so-called ‘visual word form area’. Its function is the rapid and automatic recognition of letters and words present in the proficient reader. According to one model [18], children learning to read use the parieto-temporal system to sound out new words and then, with increasing reading experience, the parieto-temporal system begins to instruct the visual word form area to recognize orthographic patterns.

“These insights have provided a completely new idea about the development of reading. As the child learns to read, it combines two functional brain circuits that exist in the pre-reader—visual recognition and auditory word recognition—to form a new integrated circuit,” explained Bruce McCandliss, Patricia and Rodes Hart Chair of Psychology and Human Development at Vanderbilt University in Nashville, USA. In contrast with some of the ideas behind the whole language approach, reading is therefore not innate; brain regions that have evolved for tasks such as object (not letter) recognition, or understanding spoken (not printed) language, need to be combined to form a new skill. Reading is, after all, an acquired human ability that emerged only after the cultural invention of the alphabet [18].

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“One of the main contributions of neuroscience in the field of reading is to develop a better understanding of how individual differences in the pre-existing systems—vision and audition of complex stimuli—pose challenges for learning to read,” McCandliss commented. The left parieto-temporal system, which supports the relation of auditory and visual processes during reading, fails to build up correctly in children with developmental dyslexia [17–20], for example. This might be due to the way in which children with

dyslexia process speech—they often have poor phonological awareness. For example, they have difficulty with oral tasks such as determining which word starts with the same sound as ‘hat’, or what word remains if you take away the ‘l’ in clap [20]. There are also children who do well in phonological processing, but have difficulties in visual processing [21].

Interventions to help children struggling to learn to read have been designed that specifically tackle the connection between phonological information and printed letters and words. “Most of these interventions predate neuroimaging studies in cognitive neuroscience and many of them have been demonstrated to be effective,” McCandliss explained. “But what is interesting about neuroscience in the field of educational interventions is that we can now move toward analysing the problem at an individual level. Neuroscience opens the possibility to address which intervention works for which child, and why.” As most remediation programmes involve intensive care and are time consuming, specific and early diagnosis is a major challenge. As John Gabrieli from the Massachusetts Institute of Technology in the USA has argued, the integration of behavioural tests and brain-based measures to predict reading difficulties is perhaps “one of the most practical, near-term synergy between education and cognitive neuroscience” [20].

There is little doubt that neuroscience can contribute to educational practices; studies of brain activity can elucidate learning processes, and this knowledge informs the design of educational programmes or interventions. But there is more to come. For example, cross-cultural comparisons have raised questions that might guide future research. It has been shown, for example, that reading impairment in Chinese—a logographic language, in which the characters represent whole words or parts of words—has a different biological origin to dyslexia in alphabetic languages. Chinese dyslexic readers show reduced activation in brain areas required for visual attention, but not in areas typically affected in alphabetic languages [22]. Does this imply that different remediation programmes should be used for Chinese in comparison with English dyslexics? In addition, it has been shown that there is a difference in brain activation between Chinese and English participants involved in

numerical tasks [22]. Can this be attributed to different teaching methods?

Reading and mathematics are arguably the areas in which neuroscience has had the most prominent impact on education. This might result from the fact that acquiring these skills is characterized by clearly defined changes in brain circuitry, which can be studied relatively easily by using neuroscientific methods [23]. But there are other aspects of education to which neuroscience can contribute. For example, attention and emotion affect learning in a general way, such that a better understanding of the neuronal underpinnings of these brain functions has the potential to have an impact on educational strategies at school.

In a seminal paper on the topic of neuroscience and education, John T. Bruer, the former President of the James S. McDonnell Foundation in St Louis, Missouri, USA, argued that attempting to link neuroscience and education directly is a “bridge too far” [1]. But he also maintained that the gulf between the disciplines might be overcome by two other bridges: one between education and cognitive psychology, and one between cognitive psychology and neuroscience. Meanwhile, traffic along these bridges has intensified, as close collaboration is essential for educational neuroscience to progress. The value of neuroscience for education is best realised when paired with cognitive psychology and educational research. Jumping to conclusions directly from neuroscience creates the risk of new neuromyths. Neuroscience can contribute to education, but expectations should be managed carefully.

CONFLICT OF INTEREST

The author declares that she has no conflict of interest.

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