The Mathematical Brain

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Introduction

The development and discussion of a clearer picture of the impact of sound pedagogies and a Model of Personal Numeracy (Fig. 2.1) that take into consideration various differences in student understanding and learning have been targeted at the teaching and learning of mathematics and numeracy as focus curriculum areas. The Model of Personal Numeracy may even contribute to an understanding of the complex, intertwined numeracy and mathematics relationship. However, that does not necessarily mean that all students find it easy to develop skills in mathematics or numeracy or even that teachers find this a simple discipline to teach effectively to every child. There are always personal differences amongst the students which include diverse learning competencies and differences, attitudes and values and other, non-specific characteristics that somehow get in the way of successful learning in these areas for individual students. Amongst these individual traits that may baffle or frustrate both the learner and the facilitator of the learning are some extreme social and cultural conditions and some biological, but frequently unseen and only recently investigated barriers to learning in mathematics and numeracy. Many of the social barriers are linked to extreme poverty and its impact on affect, cognition, academic confidence and subsequently, academic achievement.

Others may be less socially mediated in terms of socio-economic status but may be created by social pressures and expectations, perhaps in classrooms and in the communities, or as the result of certain predispositions in personal development and confidence. Many of the more recently recognised physical barriers relate to the brain and its ways of working. These are only able to be investigated in terms of the findings of a relatively recent science which has facilitated investigation into the brain and its functional capacities; that of neuroscience. It is important that each of

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these categories of difference that have the capacities to impact negatively on learning in mathematics and numeracy as dedicated aspects of classroom curriculum be discussed and evaluated in relation to supporting each student's efforts to become numerate and to fulfilling the responsibilities that every teacher has to find ways to scaffold and to encourage competencies this particular literacy. This literacy (quantitative literacy) pervades every aspect of the world in which students interact currently and will inherit in the future.

The Workings of the Brain in Numeracy

A consideration of the nature of the brain and how it works may appear to be outside the scope of teachers' professional learning but that may change with the current development of neuroeducation or a focus on brain, mind and education (Ansari, De Smedt, & Grabner, 2012), particularly with reference to developing numeracy competencies and mathematical skills (Butterworth & Walsh, 2011). Additionally, the work of Mc Gilcrest (2009), which posits that the right and left sides of the brain have different functions, may explain in part why teaching and learning in mathematics has been thought to be a separate area of study and is rarely integrated into other content domains to provide a holistic view of mathematical thinking and understanding. In arguing that the western world has been dominated and developed by centuries by the detail of left brain thinking, Mc Gilcrest (2009), may be explaining the dominance of mathematical teaching and learning which focusses more on the learners capacities to work with number calculations and formulae, rather than investigating the breadth and depth of the relationships that mathematics has with every person in their everyday lives, thus placing mathematics in the bigger picture of numeracy skills, cognitive capacities and reasoning processes that develop flexible thinking and promote the skills of effectively developing and using students' working memories.

So, an understanding of some very basic brain facts can be very helpful as teachers attempt to understand students' own constructions of mathematical understandings and numeracy competencies. There is not necessarily the need to know and understand the physical structure and the chemistry of the brain in a medical sense but some very basic understanding can be useful. The brain is the site of all cognition (the ability to acquire knowledge by using reasoning, perception and other mental faculties) and understanding it is an important aspect of knowing how students learn best and how teachers can effectively prepare and implement appropriate learning tasks to develop competencies in numeracy. This is despite the fact that only a tiny percentage of brain research is relevant in educational contexts (Jensen, 2005). At times student learning appears to happen instinctively and with little apparent effort. This may be why, as yet, studies into the workings of the brain are not having a significant impact on educational systems, learning environments or curriculum development. Another reason may be that the entire picture of how learning takes place is not yet available (Jensen, 2005). Despite this, findings from neuroscience have been used to contribute to significant advances in the teaching of academic skills in mathematics and to establish the interdependence of emotion and cognition (Immordino-Yang & Feath, 2010; Souza, 2010). It is known that from the very first cell division foetus in the womb there is an intricate balance between genetic inheritances and environment. This has clear implications for brain development.

Lipina and Posner (2012) found that conditions of poverty such as overcrowding, hunger, stress and fear of physical harm had could have a negative impact on brain functions which support academic learning, as could non-stimulating environments. This is because the brain is literally created by experiences. All types of sensory experiences, visual, auditory, tactile, physical, gustatory and olfactory, create imprints on the brain which are represented as a series of images (Suarez-Orozco & Sattin-Bajaj, 2010). The brain even starts life with capacity for emotional responses, which can later be educated to respond appropriately to moral and ethical challenges. These emotions and feelings have images that are based in the body itself as opposed to the responses elicited by outside stimuli. 'Images are the currency of the mind' (Suarez-Orozco & Sattin-Bajaj, 2010: 61) and the owner, interpreter and 'comprehender' of the mind is the 'self'.

Equally important is a cursory understanding of the brain's structure. There are four lobes in the brain; the temporal, frontal, parietal and occipital. The outermost layer of the is called the cerebral cortex and covers the cerebrum, and the front part of the brain (Blakemore & Frith, 2005b). The cerebral cortex is often termed 'the grey matter' and is the most highly developed part of the brain. It is the critical component in the learning process. It is divided into left and right hemispheres. There is, as yet, no complete understanding of the precise function of each of the two hemispheres of the cerebral cortex, which are joined by clusters of nerve fibres known as the corpus callosum and the anterior commissure, which also facilitate communication between the two hemispheres. However, it is known that different parts of the brain are used, either independently or more usually in coordination with other parts of the brain, for different types of learning (Gardner, 1993a). For example, the hippocampal system, which is located in the temporal lobe, is concerned primarily with learning facts. The cerebellum and the basal ganglia, which can both be found under the cerebral cortex are the locations responsible for the development of skills. Blakemore and Frith (2005b: 78) indicate that the learning required for reading and writing related skills are located in three areas of the brain. Unfortunately, the areas of the brain that process mathematical thinking are not as easily identified (Davis et al., 2009) and this has the impact of limiting what teachers know about how students construct mathematical skills and numeracy competencies.

What is known is the human brain has innate number sense, concepts of discrete whole numbers, the capacity to distinguish a correct from an incorrect answer when the scenario involves arithmetic and small whole numbers and that numbers and arithmetic beyond three require the use of language (Devlin, 2010: 164). Although there is no one area of the brain that is responsible for all the different types and components of learning and processing in mathematics, the parietal lobe is the lobe associated with spatial representations, sense of direction, locating objects in time and space and with numbers and their relationships. Davis et al. (2009) also found that the parietal lobe became more specialised for computing arithmetic tasks with as students became older and entered adulthood. Exact calculations also appear to be processed in this area of the left hemisphere but the capacity to process approximation of number appears to be located in a different area of the brain altogether, which is in the right hemisphere. Although the brain actively seeks and recognises patterns and both hemispheres are able to compare numbers, only the left hemisphere can add and multiply. Interestingly, there still exist some difficulties in locating the exact sites of some other 'non mathematics specific' areas of learning. For example, theorists present some differences in their understandings of where the skills of reading music are located. Jensen (2005) indicates that reading music activates both sides of the brain. Blakemore and Frith (2005a, b), however, report the findings of a study that located these skills in the same area of the parietal lobe that facilitates spatial awareness.

In the development of quantitative thinking itself, as indicated, infants have been proven to possess innate number sense in terms of distinguishing quantity (Berninger & Richards, 2002; Lipina & Posner, 2012). The difficulty is however, harnessing that potential. As Devlin (2010: 163) comments

Mathematics teachers—at all education levels—face two significant obstacles

- We know almost nothing about how people do mathematics.
- We know almost nothing about how people learn mathematics.

Berninger and Richards (2002: 196) are able to add some information regarding the beginnings of mathematic thinking. They describe the notion of 'true counting' where children are able to use one-to-one correspondence as an indication that they have created an 'internal' number line and thus have started the process of rudimentary and complex mathematical thinking such as 'place value, the concept of infinity, negative numbers and prime numbers'. There are however, disputes over the location of this in the brain (Lipina & Posner, 2012). Berninger and Richards (2002) suggest that this thinking can also be supported by the use of an external number line to use as a tool. They assert that eventually, most students develop and learn to manipulate more than one number line and this facilitates the control and interaction of multiple quantitative dimensions at the same time. Importantly, they indicate that for these mental models of number lines to become more complex there must be present the capacity for 'crosstalk' between the various parts of the brain which perform different functions. Using current research, Berninger and Richards (2002: 205–206) have identified possible sites of diverse mathematical activity. Unfortunately, a number of mathematical functions that are critical to the development of numeracy competencies are still listed on this table as 'unknown'.

However, more recent research has begun to help close this information gap. Cragg and Gilmore (2014) summarised the various findings from diverse studies which involved investigating any potential relationship between strategies to strengthen specific cognitive capacities in the executive function domain (see Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Bernstein & Waber, 2007; Dendy, 2002; Isquith, Crawford, Espy, & Gioia, 2005; Meltzer, 2007; Moran & Gardner, 2007; Sellars, 2009). The studies they examined involved participants in various ranging from 5–12 years old. They indicated that they found strong evidence that the executive function capacities of working memory, flexible thinking, impulse inhibition and self-monitoring were all important capacities in children's mathematical development of facts procedures and concepts. The particular impact and importance of each of the cognitive capacities varied amongst the students according to development stage, activities undertaken and the mathematics proficiency of the individual students.

The degree of neurological activity associated with the cognitive capacities of working memory also proved to be an accurate predictor of the ease with which students could learn new mathematical knowledge. They concluded that the precise ways in which these domain general cognitive skills facilitated improved mathematical understandings was not entirely clear at this time, however, if students' mathematical progress were assessed in terms of their achievement in factual, conceptual and procedural knowledge instead of the standardised testing that is currently implemented, more critical information would become available to support and inform classroom practice. As both mathematical ability and executive function skills improve throughout the developmental stages of individual growth, another important issue for this research was to pinpoint how the relationship of these cognitive capacities of executive function impact differently at assorted ages and in different mathematical domains. Working with college students to determine the relationship of domain general cognitive capacities (executive function skills) and domain specific skills (mathematics, in this case complex arithmetic), Ashkenazi, Golan, and Silverman (2014) found that strong executive function capacities can compensate for poor mathematical acuity in complex arithmetic tasks.

Other investigations into working of the brain promise to be of benefit to mathematics educators in the early stages of learning. Until very recently, it has been difficult for neuroscientists to pinpoint exactly which areas of the brain were involved in mathematical activities. However, findings from neuroscience research has been able not only to identify regions of the brain that are involved in mathematical activities, but have recently ascertained the functional circuits that work together to facilitate mathematical learning (Evans et al., 2015). Bassett, Yang, Wymbs, and Grafton (2015) also investigated the importance of the neural connections and distributions in the brain during learning for therapeutic, non-invasive purposes. This work also has potential for enhancing teaching and learning. Neuroscientific findings have also established that board games and electronic games that have both symbolic and non-symbolic (dots or drawings to indicate magnitude) are critical for students at risk of developmental dyscalculia or a typical numerical development (De Smedt, Noel, Gilmore, & Ansari, 2013), that physically doing activities supported the development of complex abstract representations in number activities (Link, Moeller, Huber, Fischer, & Neurk, 2013) and that the ways in which numbers are expressed in different languages affects the ways in which adults process arithmetic (Lonnenmann & Yan, 2015).

The fact that there are still aspects of thinking that not able to be located in the brain but are required for competency in mathematics and numeracy can be an important factor that impacts on teachers' efforts to support student learning. To further complicate matters, all the components of the 'computing' brain (the mathematical parts of the brain that are identified) do not develop at the same pace (Berninger & Richards, 2002; *The Josset Bass Reader on the Brain and Learning*, 2008). It is suggested that genetic, social and cultural diversity may have an impact on the maturation of various parts of the brain and on the associated capacities to function effectively in relation to other elements. A number of competencies that are required to coordinate together for effective processing; such as capacity for sustained attention, visual skills and the coordination and physical skills of writing; may impact on the capacities of the components of the computing brain to work together effectively or not. It is also possible that there is a mismatch of competencies. For example, children know more about the number system than they can express using the standard symbolic notation or that students appear to have achieved successful prior learning in regard to number but they actually have factual but no conceptual understanding of what is required. The other influential factor is that students may have 'wiring anomalies' (Lipina & Posner, 2012: 209) that need to be investigated.

What does this mean for you as a teacher of numeracy?
While the brain is very complex and is still being investigated, there are some clear implications for professional practice. These include:

- An understanding that all experiences, good or otherwise are part of creating the brain. Successful learning experiences and those that are not successful have equal impact.
- There is limited specific knowledge relating to how individuals learn or do mathematics, making the work of the mathematics teacher less informed in terms of how the brain functions exactly in their area of knowledge.
- As different parts of the brain exhibit a readiness to learn at different times, it is important that learners are encouraged to undertake appropriate tasks. It also means that tasks which appear too difficult are reserved until the part of the brain that facilitates this learning is ready to be active in the learning process. Students need to be encouraged to believe that they will achieve various tasks when they are ready and not to suppose that they will never be good at the area that they are finding difficult at any moment in time.
- Understanding the concept of one-to-one correspondence is critical to mathematical thinking.
- Relating new ideas to previous knowledge is very important in the learning process. Learning occurs all the time, so learning outside the

classroom context is an important source of reference on which to base related, new learning as the synaptic occurrences make the learning easier on that pathway.

- Sequencing is important. In order to give students the best opportunity of learning successfully, ideas and knowledge, strategies and procedures should be taught in as logical, ordered, relational fashion as possible, even though all learning is not linear.
- Because the brain changes in structure with each new learning experience (Berninger & Richards, 2002). It is often necessary to teach the same concept in different ways because novices' (students) brains are organised differently one from another and from their teachers. This is because of the density of learning experiences in the brain of the teacher which is not yet present in the brain of the learners. It is also because experiences are personally mediated and linked, and, together with the unique patterns of wiring in each individual's brain, are organised, stored and linked in ways that are specific to the individual.
- The brain does change in response to learning. However, as everyone is 'wired' differently, it is safe to assume that none of the students will experience exactly the same changes in organisational structures, despite the common attribute known as 'brain plasticity (Souza, 2010)'.
- Given (2002) proposes that the brain is organised into five learning systems, each of which impact on and interact with each other. She names these as the emotional, social, cognitive, physical and reflective systems. Difficulties in any one or more of these can affect the brain's capacities to orchestrate the finely tuned communication that is necessary for even simple mathematical tasks.
- Parts of the brain usually coordinate with each other during the learning process.
- Only one part of the brain is utilised when learning is about learning facts. This means that other types of learning are important in any lesson plan.
- Students cannot always explain how they known various aspects of mathematical understanding as number sense is part of the brain's function, so they may just know that what they are seeing or doing is correct.
- External tools (concrete materials and number lines, etc.), can support thinking in counting and related conceptual constructs.
- *For example, the Year Three activity in Visual Arts requires students to reflect on their previous learning and select anything they feel is relevant to the given task. The relevant information may include conceptual knowledge about shape, relative quantity and the appropriate vocabulary to describe and discuss this knowledge. This recall and reasoning process is identified as a cognitive activity. In the task, the students need to actively deconstruct and reconstruct an image by interacting with physically as well as cognitively. Students find this easier when they are engaged positively (Fredrickson, 2001) and this task promotes social*

interactions as students are encouraged to work together to share their creative ideas, to discuss the metalanguage, to investigate using trial and error and to continually make decisions about the results based on prior learning and on the learning that is taking place. Any mathematics activities where students are physically manipulating materials, investigating, discussing prior knowledge and language in groups, and where they are not threatened by fear of failure or criticism has the potential to engage all the proposed learning systems (Given, 2002).

Impact of Individual Differences in Brain Development on Numeracy

Differences in environment impact on the brain's capacity for learning. One of the most powerful environmental differences can be related to socio-economic status and the impact that living in poverty can have on the brain (Janus & Offord, 2007) considering the substantial impact of home numeracy experiences on later learning in mathematics (Kleemans, Peeters, Segers, & Verhoeven, 2012; LeFevre et al., 2009; Manolitsis, Georgiou, & Tziraki, 2013) and the advantages gained in terms of students' scores in primary mathematics by children who have the opportunities of engaging with numeracy experiences at quality preschools (Melhuish et al., 2008, 2013). Limpina and Posner (2012) reported that students from low socio-economic backgrounds who participated in their study did not have a great an understanding of quantity as students from other, more financially secure backgrounds. Given the importance of understanding quantity to the beginnings of mathematical thinking, there are clear implications for these students in relation to their capacities to succeed in mathematics at school as the Australian Early Development Index, which is implemented at age five, has been shown to be a reliable indicator of student performance in mathematics during the primary school years (Brinkman et al., 2013). However, Limpina and Posner did also find that early training in board games, computer games and manual activities that developed the students' capacities in numerical quantities had the capacity to mediate the impact of this deficiency and lessened the risk of the students failing in primary school mathematics (Ramani & Seigler in Limpina & Posner, 2012: 8 Interestingly, results from another study reported by these authors found that the positive impact on student learning was restricted to one aspect of number sense competencies; their capacities to compare numbers and words (Wilson et al., in Limpina & Posner, 2012: 8). Despite the differences in the findings of these two studies, a third numeracy intervention study conducted across five kindergarten classes in a low socio-economic school indicated that the students 'at risk' in numeracy who participated in the programme benefitted in terms of all the aspects of numeracy sense (Sood & Jitendra, 2013).

The findings that students from low socio-economic environments had less well-developed concepts of quantity may be explained in terms of limitations of language development (Walker, Greenwood, Hart, & Carta, 1994) or other circumstances associated with low socio-contexts. In addition to these language considerations, Limpina and Posner (2012), in their investigations of low socio-economic pre-schoolers also discovered some very interesting cultural differences. The students who were Chinese native speakers used different parts of the brain to complete the same tasks as those who were native English speakers. This anomaly may be the result of social, genetic or experiential differences and is as yet, unexplained. It is known that the brain needs, for example, like other parts of the body, to be kept healthy through adequate nutrition (Taras, 2005). The impact of overcrowding, hunger, mental stress and perhaps fear of physical harm has the potential to have a negative influence upon the development of the brain during childhood and later in life (Lipina & Posner, 2012). The lack of complex, rich environments for children to interact within may alter the brain's potential to adapt easily and meet the challenges of new contexts. Even sleep deprivation can have a severe negative impact on the brain and learning as it interferes with cognition, decision-making, reasoning and innovative thinking (Blakemore & Frith, 2005a). It seems that, during sleep, the brain reactivates the regions that are used for learning during day and interrupted or poor quality sleep interferes with that regenerative learning process.

The quality of the learning environment is another area in which contextual variation impacts on students' capacities to learn effectively. Recently, a focus on positive learning environments (Seligman, Ernst, Gillham, Reivich, & Linkins, 2009; Seligman, Park, & Peterson, 2005) has indicated that students achieve more successfully if their learning contexts are positive and supportive (Noble & McGrath, 2008). This evidence supports the work of Souza (2010) that indicates that the human brain is unable to think unless it is in a 'safe' environment and of Given (2002), who has explored social and emotional learning systems and their influence on each and the other systems that are focussed on learning. This research is also validated by the findings of researchers in other disciplines associated with learning and education. These include the work of Fredrickson (2000, 2001) whose '*Broaden and Build'* model was developed from her research that clearly indicated that the capacities for the cognitive skills associated with problem solving and creativity were able to be enhanced by the provocation of positive emotions. The importance of the influence of emotions on the potential for the successful development and access of cognitive capacities has been well explored in the contexts of emotional intelligence theories (Bar-On & Parker, 2000; Goleman, 1995; Mayer & Salovey, 1997; Mayer, Roberts, & Barsade, 2008). It has also been a component of the exploration of the intrapersonal intelligence domain of Gardner's Multiple Intelligences Theory (Gardner, 1993a) which demonstrates the effect that the positive engagement trait of executive function has, not only in relation to effective cognition, but also in regarding self-regulation and monitoring of behaviours. Teaching and learning in positive contexts and environments certainly appears to support effective cognition. In contrast, one of the most widely recognised consequences for students who do not enjoy teaching and learning in mathematics is the degree of anxiety that was associated with this subject area.

The investigations that were carried out by Limpina and Posner (2002) revealed that, as the tasks the pre-schoolers were asked to complete became increasingly complex, the English native speakers activated parts of the brain associated with anxiety and negative effect. The Native Chinese speaking pre-schoolers did not. Whilst the reasons underpinned these differences are yet to be discovered, if the variation were to be identified as a dissimilarity in preschool education or training, that certainly would have significant implications for teachers and their mathematical pedagogies. It could also lead to the routine screening of students' brain activities and anxieties after they had participated in intensive teaching programmes designed to increase their numeracy skills (Cohen Kadosh, Dowker, Heine, Kaufmann, & Kucian, 2013). However, whilst this will certainly be useful teachers and their students, it may reveal that certain groups of students are more prone to mathematics anxiety than others and that ways to support these students in regular classrooms need to be developed from research and able to be implemented by teachers in the contexts of their regular classroom practices.

Sheffield and Hunt (Sheffield & Hunt, 2006, 2007) have defined maths anxiety as feelings of tension, apprehension fear or anxiety and have noted that maths anxiety is not confined to students studying arts subjects, it is also found in students who are studying in areas that require specialised mathematical knowledge. The impact of this anxiety is twofold. First, students may avoid mathematics and fail to develop sufficient conceptual understanding on which to build robust knowledge. Second, they feel so anxious whilst completing mathematical tasks that their working memory, on which many complex calculations heavily rely, becomes distracted and affects their performance. Westwood (2008: 11) whilst discussing the importance of capitalising positively on children's interest and competencies in numeracy during their early years, stresses the role of the school in fostering learning in this area or by 'snuffing out' any positive student inclination by engaging students with mathematics in ways in which they experience failure. This situation can be compounded by the expectation that students engage with mathematics homework. Lange and Meaney (2011) reported incidences of severe emotional trauma in cases where parents are unable to support students with their mathematics homework. They identified a number of reasons why this might occur. They suggested that parents did not always have the skills and knowledge to support their children or that perhaps that the means by which the parents explained the concepts, strategies or knowledge was different to the way their children were learning at school. Either of these situations could lead to emotional trauma for both the parents, who had been placed in the role of teachers as mathematics as a discipline, and for students whose brains associated learning in mathematics with failure, distress and negativity. A further disadvantage was that, by engaging in activities that were based on formal mathematical procedures in the home, the students were not able to use this time to engage with their parents in order to explore genuine opportunities to become more numerate.

What does this mean for you as a teacher of numeracy?

- Perhaps the most important overall finding of neuroscience is the need for the brain to be emotionally safe for cognition to occur. This knowledge informs both the nature of the optimum learning environment and the quality and nature of classroom interactions and teacher–student relationships. The less stress and anxiety that student experience, the more able their brain is to learn, so being positive is important. Positive learning environments can support the interaction of the five learning systems so they are mutually productive.
- Teaching and learning in early years numeracy is an essential aspect of beginning successful mathematical thinking.
- Students from low socio-economic backgrounds may have numeracy difficulties that are compounded by their language capabilities.
- There are cultural differences in ways in which diverse parts of the brain are activated during mathematical and numeracy tasks.
- The entire body is involved in learning. Physical health and activity is significant in the learning process as are the ample, appropriate provision of opportunities for sensory experiences.
- Students who are not well nourished, are sleep deprived or afraid, distressed, anxious or otherwise unhappy are unlikely to be able to learn as effectively as those who have nutritious diets, adequate sleep and feel safe in the learning environment. It is difficult for them to fulfil their full learning potential, even if they are otherwise motivated to learn.
- Creativity is important for effective learning as it coordinates parts of the brain not utilised together in more ordered, convergent thinking. It facilitates the investigation of problems and generates new plans and designs for solving these problems by engaging students in divergent thinking.
- Mathematics homework may easily be counterproductive or act as a deterrent to the development of mathematical skills and numeracy competencies.
- *For example, engaging in any of the activities which involve students creating their own versions, notions or models of activities would be useful. Tasks such as the ones detailed in the Health lessons support the understanding of healthy lifestyles for optimal learning. The Year 5/6 Dental Health lesson investigates alternative methods of maintaining oral hygiene, (which some students may regard as a boring twice daily chore). The tasks have a creative component as students may make variations to their teeth cleaner recipe and, irrespective of the taste, none of the resultant cleaners are incorrect—the mathematical challenge may be to alter the proportions of the recipes to make the products more palatable!*

Atypical Brain Wiring and Its Impact on Numeracy Development

Although learning problems in developing numeracy competencies are estimated to be more frequently (Ansari & Karmiloff-Smith, 2002) than problems in literacy, numeracy problems have not attracted as much research or educator attention as those related to literacy. Students with otherwise normal development patterns who exhibit substantial, ongoing problems with arithmetic are said to be suffering from numeracy deficiency or dyscalculia (Ansari & Karmiloff-Smith, 2002). (Berninger & Richards, 2002; Cohen Kadosh, Dowker, Heine, Kaufmann, & Kucian, 2013; Landerl, Bevan, & Butterworth, 2004). Dyscalculia can be developmental or acquired. Developmental dyscalculia is not associated with head trauma, acquired dyscalculia is the result of this trauma (Munro, 2003). This deficiency is not believed to be result of other deficiencies, such as dyslexia (Bevan, Butterworth & Landerl, 2004) although they are frequently found together and there is a strong relationship between numeracy and literacy development in the early years (Kleemans, Segers, & Verhoeven, 2011; Neumann, Hood, Ford, & Neumann, 2013; Purpura, Hume, Sims, & Lonigan, 2011). Research indicates that students who suffer from both dyscalculia and dyslexia have significant differences compared to students who suffer from dyscalculia alone (Ansari & Karmiloff-Smith, 2002) and that these two disorders are often accompanied by Attention Deficit Disorder, which adds further complexity to the strategies used to support students with dyscalculia as they cannot be considered to be a homogenous group. It appears that students who suffer from developmental dyscalculia may often be suffering from a number of other learning disadvantages (Landerl, Gobel, & Moll, 2013).

Ansari and Karmiloff-Smith (2002: 511) describe numeracy as a ‘particularly vulnerable cognitive domain in the atypically developing brain’ and note it is particularly prevalent in genetic disorders and children born preterm, despite other areas of learning and scales of intelligence being scored highly. It has been found that children born preterm had less grey matter in a specific section of their left parietal lobe than children who do not have numeracy difficulties. The focus of the rather frugal amount of research on dyscalculia has appeared to focus predominantly on number specific actions like number operations, However, where research is has been focussed on the impact of dyscalculia in less specific learning domains, it had been found that students (i) have immature problem-solving strategies (Harris & Ford, 1991) (ii) have poor working memory span leading to computational errors (Harris & Ford 1991) (iii) deficits in long-term retrieval of arithmetic number facts (iv) slow processing speeds (v) disturbances of visual-spatial functioning (Ansari & Karmiloff-Smith, 2002: 514) which impact on all domains including numeracy.

What does this mean for you as a teacher of numeracy?

- Dyscalculia is at least as prevalent as dyslexia. Some children may have both difficulties; some may also have Attention Deficit Disorder and others may have multiple learning difficulties. However, premature decisions regarding the identification of students with dyscalculia is not only unhelpful for the students, but outside the expertise of most teachers, so professional support would be required for the diagnosis and strategic support of students suffering from dyscalculia in much the same way as it is for students with dyslexia.
- Incidences of dyscalculia are prevalent in **some** genetic disorders and amongst students who have been born preterm.
- There are two types of dyscalculia, one is developmental and the other is acquired.
- Dyscalculia is not confined to numerical calculations but to other skills that are important for learning across the curriculum.
- The working memory and other cognitive capacities of executive function skills are important aspects of learning in numeracy so even very young children can benefit from activities designed to strengthen working memory skills and other executive function skills, especially in the parietal lobe.
- Dyscalculia impacts across all learning as it impacts on all the diverse aspects of numeracy, not just numbers and calculations.
- *For Example, to support students with any of the learning characteristics mentioned above, activities which are ongoing, which have a concrete component, are non-competitive and which do not rely heavily on speed of completion and oral instruction would be useful to the learner. The English lesson for Foundation students, Animal Alliteration, for example, allows students to participate with lots of repetition, is not fast moving, has several reminder clues and cues and is a group activity. Instructions are simple and are repeated each step of the way so that students can feel confident. Variations to this task can be group or activity based to allow specific students more support or more time to complete a list of what they see in diverse, familiar contexts. This can be further supported by providing the visual representations of what the students may see in the context being discussed. The dots on the dice facilitate the development of 'counting on' and doubling strategies which involve both additive and multiplicative thinking and can be easily made more complex by making and using home-made dice with bigger numbers for older students.*

Conclusion

This chapter investigated the workings of the brain that are currently known in relation to the development of numeracy and mathematical learning. It also introduces the idea of 'neuroeducation' as an essential component of studying how best to facilitate learning. Learning depends on the brain's capacity to integrate and orchestrate activity in many parts of the brain to perform even simple tasks in numeracy. The two hemispheres of the brain are constantly and instantly in communication with each other via the nerve clusters of the corpus callosum and the anterior commissure but the exact organisation and brain activation of many areas of mathematical skills and capabilities and numeracy competencies cannot be identified at this stage, despite their undoubted importance to educators in general and teachers in particular. The area of the brain identified as the parietal lobe has been recognised, however, as being of particular significance in the development of mathematical skills and numeracy competencies. An important consideration, however, may be the confirmation of the significant impact that emotions have on learning; confirmation of the knowledge that the brain cannot function effectively or efficiently unless it 'feels safe' (Medina, 2010; Sousa, 2010). Negative feelings and contexts will not facilitate optimum, learning in numeracy or mathematics, either in school or at home. Other circumstances, such as the low socio-economic backgrounds of students and cultural diversity and the subsequent impact on the students' brain development in innate and developed skills in quantity have been indicated. The importance of early numeracy skills have been highlighted by Limpina and Posner (2012) including the essential nature of students' capacities in the concept of one to one correspondence. Additionally, the notion of dyscalculia, the incidence of dyscalculia and dyslexia, both together and with additional disadvantages in the brain; and the subsequent impact on the successful acquisition of mathematical concepts and numeracy skills applied across the diverse areas of learning in classrooms, had been introduced.

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