BASIC THEORY OF EDUCATIONAL NEUROSCIENCE FOR MATHEMATICS TEACHERS – A REVIEW

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ABSTRACT – This paper is a review of how the knowledge of educational neuroscience by teachers of mathematics and its inclusion in mathematics teacher education curricula can enhance our understanding of how students learn mathematics. It is premised on studies that point to two of the obstacles that teachers of mathematics face, that is we know almost nothing about how people do mathematics and we almost know nothing about how people learn how to do mathematics. Teachers' understanding and knowledge of what goes on in the brain and mind as learners grapple with mathematical concepts and facts could enhance the way we teach and disseminate mathematical information. Teachers' knowledge of educational neuroscience will also dispel neuromyths - a presentation of facts with little or no scientific bases about the science of the brain, memory and learning

Keywords: Educational Neuroscience; memory and learning, mathematics learning, neuromyths

INTRODUCTION

This paper explores the introductory educational neuroscience relevant to teachers of mathematics. It explains the underlying neural functioning principles of mathematics instruction and provides neural explanations of the essence of reviews of previously leant mathematical content and reinforcement of instructions through assessment such as classroom exercises and home work. There is marked evidence that brain based research is finding it way in the teaching as well as intervention approaches that enhance mathematical knowledge acquisition (Tibke, 2019; Howard-Jones, 2010; Cohen Kadosh, Dowker, Heine, Kaufmann & Kucian, 2013). Development in the interest of the application of neuroscientific discoveries to educational practice go back four decades ago (Sousa 2010). In 1983, Leslie Hurt in her now classic works *Human Brain and Human Learning*, wrote *'teaching without awareness of how the brain learns is like designing a glove with no sense of how the hand looks like' (p.13).* This statement implies that teachers' understanding of how children grapple and understand mathematical concepts is critical in ensuring effective mathematical knowledge acquisition. Almost in the same vain, Ansari (2010:128) posted that *I would contend that the most effective way of bringing neuroscience into the classroom is to provide teachers with access to knowledge that neuroscientific studies are yielding. This knowledge will inform teachers' conceptualization of the learning . . . And therefore their pedagogical approaches*. These are very important quotes that point to the rationale of teachers' knowledge of basic neuroscience. Advocates of educational neuroscience (Verschaffel1, Lehtinen & Van Dooren 2016; Sousa 2010 Stern & Schneider, 2010) have however hinted at some of the skepticism that neuroscientists hold about teachers being exposed to neuroscience, however rudimental it maybe. This paper advances and expose the theories of educational neuroscience, especially the science of learning and memory that are pivotal in teacher education curricula because of the various outlined benefits such knowledge would bring to the teachers. It is believed that findings of cognitive neuroscience can be helpful to educational theory. There are however critical proponents of the move to engage neuroscience together with education being that such ambitions are predominantly influenced by cognitive neuroscientists and less so by educationists and the interactions are unidirectional (Turner 2011). The reasons for this one-sidedness is that neuroimaging research outcomes on mathematical cognition for instance, are less open to critical evaluation by educational scientists (De Smedt, Ansari, Roland, Hannula- Sormunen & Schneider, 2011).

BASIC BRAIN ANATOMY FOR TEACHER

Developments in imaging technology have propelled development in cognitive psychology and neuroscience (Purves, Augustine, Fitzpatrick, Hall, LaMantia & White, 2012). Before then cognitive scientists drew conclusions about brain growth or development by watching how the subjects acquired certain skills, neuroscientists could only infer about brain functions by looking at case studies from patient traumas, strokes and lesions of haemorrhage. The brain could only be studied in an autopsy. The information collected could only inform neuroscientist about where in the brain structures something happened but not the function of the brain. Machines such as the X-rays only revealed hard tissue such as bones and also damaged health brain cells. The Computerised Axial Tomography CAT or CT scan came into use in the 1970s, it had lower X-rays and was able to show variations in soft body tissues. The major breakthrough in medical diagnosis of the brain came with the use of the Magnet Resonance Imaging in the 1980s. These were great for medical diagnosis of the brain traumas by showing the structures that were affected, but what the scientists needed most was technology that would reveal the function of the brain. The functional Magnet Resonance Imaging (fMRI) was the answer (Purves et al. 2012).

The discovery in the 1970 to 1980 about the brain being made up of various regions that functioned independently formed the basis for explaining why different learners have different learning styles and that began the movement to link pedagogy to neuroscientific discoveries (Sousa, 2010). Educational implications in neuroscience and mathematics attest that teachers of mathematics could benefit from knowledge of brain and its basic circuitry (Sousa, 2010; Verschaffel, Lehtinen & Van Dooren, 2016). The brain is part of the Central Nervous System. There are currently more than 10 trillion known connections between neurons in the human brain that can produce varied behavioural capabilities in a human being (Taylor, 2010, p. 48). That means there is still a lot to learn about the brain. In a learner's attempt to acquire a mathematics concept, there are several parts of the brain that are called into action. The three main parts of the brain cerebrum, the cerebellum and the brain stem are all in one form or another involved when mathematical information is relayed to the brain (Purves et al. 2012). The cerebrum is divided into two parts the right and left hemispheres. The four lobes, Frontal, Parietal, Temporal and Occipital are part of the cerebrum. Figure 1 indicates the core parts of the brain that a teacher of mathematics should be aware of when providing instruction. The thalamus is the part of the brain that relays information from the sensory organs (eyes, ears, skin, tongue and nose) through the sensory neuron to the cerebral cortex which is responsible for complex thought processing such as mathematical cognition (Purves et al. (2012). The brain communicates with the support of neurons or nerve cells as they are sometimes referred to.

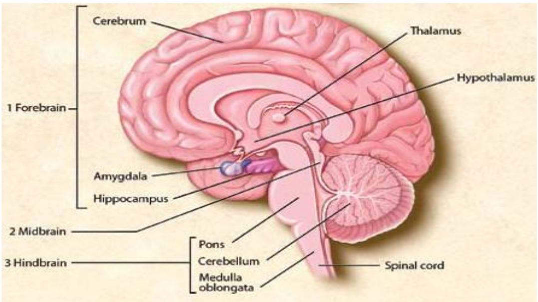

Figure 1: Image of the Brain from *Brain Facts: A Primer of the Brain and the Nervous System*, p.5. 2008 Society for Neuroscience

THE NEURON DOCTRINE – BACK GROUND KNOWLEDGE FOR MATHEMATICS TEACHERS

The neuron is a cell that is made up of the nucleus, cell body the Selma, dendrites and the axon. The neuron doctrine was expounded by a Spanish neuroanatomist by the name of Santiago Ramon Cajal (1852-1934). He used the Golgi staining technique to individualise the cells and pointed out that cells have each got a separate morphology and not a continuous process or system as was earlier defined by Camillo Gogil an Italian neuroanatomist with the reticular theory that advocated that cells morphology were continuous. Cajal using Golgi staining method expanded on the structural molecular uniqueness of neurons and their connectivity with other cells via the synapse (Poo, 2011).

Research (Purves et al. 2012) show that most of communication in the brain is transferred from one neuron to the other as an electro chemical impulse called action potential. The action potential is the signal by which cells (neurons) communicate in the body. The brain has 100 billion neuron and no one knows the number of connections between them in the nervous system (Purves et al. 2012). There are two types of cells in the body. Neurons are electrochemical producers and transmitters and support cells such as glia cells that guard and insulate neurons. The signal in the neuron is intra cellular and passes through the axon to the neuron terminal. The electrochemical signal is due to the movement of ions which are as a result of change in potential in the cell membrane called polarisation. The change in the membrane is in response to an external stimuli such as a mathematical input. The signal as an action potential is measured in millivolts. The action potential is sometimes referred to as the propagation of a charge in the cell membrane.

AN ACTION POTENTIAL AS A MATHEMATICAL SIGNAL

When mathematical instruction such as the provision of a concept definition is provided to the learner, the message is relayed through the brain cells as an action potential but not every action potential results in learning (Poo, 2011; Purves et al. 2012). The signal travels through the axon to the nerve end of the pre synaptic cells also known as presynaptic neuron. At the presynaptic cell end the action potential potentiates the release of presynaptic neurotransmitters at the presynaptic region of the neuron cell terminal through vesicles. Vesicles carry the neurotransmitters and if the presynaptic cells are in excitatory mode and the post synaptic cells are also in the excitatory mode (excitatory synapse) the vesicles releases the neurotransmitters as chemical reactions into the region between the transmitting neuron and the receiving postsynaptic neurons called synapse. This results in synaptic polarization or depolarizing of the postsynaptic neuron. If the excitatory neurotransmitters are strong enough to reach the threshold of excitation, then the neuron will fire – an action potential that will relay the mathematical impulse further down the neuron. Through a process called reuptake the empty vesicles without neuro transmitters go back into the cell axon to start the process all over again. Figure 2 provides an illustrative explanation of the action potential at synapse that enables the release of neuron transmitters and attach to the receptors of the post synaptic neuron.

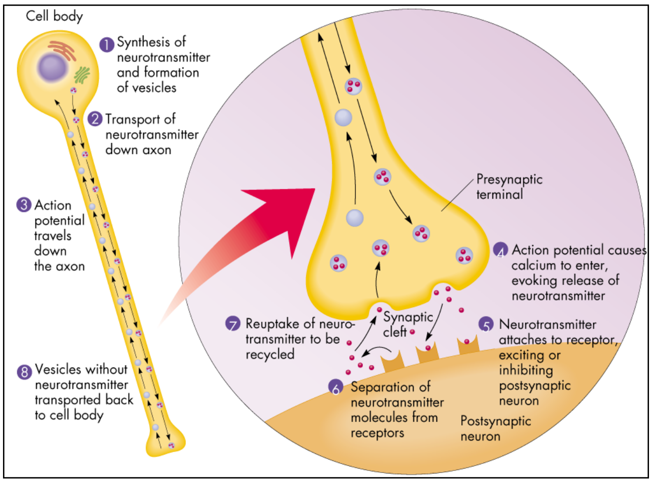

Figure 2: ***Adopted from Neuron Synapse Anthropology.net Action potential at Synapse and role of neurotransmitters and receptors***

THE CELLULAR BASIS OF MATHEMATICAL COGNITION

Mathematical cognition is the mental process and neurological engagement involved in mathematical knowledge acquisition. Mathematical cognition refers to thinking, understanding and remembering and it is the conscious mental activity conceivable in achieving aspects of awareness, perception, reasoning and judgement. Mathematical cognition is a transmitted neuronal signal. As a mathematics teachers explains a concept a mathematical signal is sent to the recipient, the learner. The signal causes a depolarisation in the neuron that leads to an action potential which is the signal unit of the reaction. Every significant mathematical explanation causes a depolarisation and an action potential.

The transmission of the mathematical signal to the next cell/neuron is due to the synaptic potential. When a group of synapses or mathematical impulses work together they causes an Excitatory Post Synaptic Potential (EPSP) in the receiving neuron. The information is gathered from different inputs to form the excitatory post synaptic potential in the receiving neuron. The persistence and continuous bombardment of the post synaptic cell with similar mathematical impulses leaves an imprint at the synapse and that is mathematical concept acquisition and memory.

NEUROLOGICAL EXPLAINATION TO WHY SOME CHILDREN DO NOT UNDERSTAND MATHEMATICS

In cognitive neuroscience the Hebb's (1949:136) learning Rule- 'Cells that fire together wire together' implied that correlated pre and post synaptic activities cause synapse to strengthen/stabilisation. In explaining mathematical learning neuroscience studies have emphasised the importance of relating mathematical content to what the learners already know, prior knowledge, as that strengthens the new mathematics and how the mathematics concepts would be understood (Howard-Jones, 2010; Tibke 2019). Uncorrelated pre and post synaptic activities cause synapse weakening or even elimination leading to mathematical concepts not being understood or concepts being quite easily forgotten (Poo, 2011). The converse is that when the mathematical stimuli causes an action potential, the synaptic connection is strengthened when Cell A keeps firing Cell B, correlated pre and postsynaptic mathematical impulse causes synaptic stabilisation or strengthen the understanding of the mathematical concepts. The postsynaptic cell is an integrator of all the pre synaptic signals or mathematical impulses and a bundle of uncorrelated mathematical signals will yield uncorrelated mathematical outcomes (Poo, 2011).

THE LONG TERM POTENTIATION (LTP) AND MATHEMATICS COGNITION

Bliss and Lomo (1973) in a now classic paper in most memory and learning studies explained in detail how similar sets of mathematical impulses or neurological stimuli that leads to understanding and memory is traced to the various regions of the hippocampus in brain cortex. In their study on the brain of a rat they discovered that a high frequency stimulation of this region of the cortex a synaptic transmission is enhanced for a prolonged period and this is memory (Bliss & Lomo, 1973). The frequent transmission (persistent mathematical input) induces the cellular changes in the hippocampus which can be explained as the trace of memory of the prolonged experiences of the mathematical impulse. The cellular change at the synapse in the hippocampus creates memory which is an electric long term trace of experience and in this instance mathematical experience causing perceptual learning (Poo, 2011). The LTP explains why in explaining mathematical concepts repeated experiences which are revision, sometimes re-teaching of the concepts and class and homework exercises would be important for memory and understanding. The cellular change at the synapse cause the perceptual learning over a longer period of time - memory. Long term memory get encoded in all areas of the cortex.

HOW RELATED MATHEMATICS CONCEPTS ARE EXPLAINED AS INDUCING LTP - Input specificity

LTP has a property that is input specific (Poo, 2011; Bears et Al. 2001) and this provides further explanations to mathematical knowledge acquisition and cognition. The studies (Bears et al. 2001) explain that if the hippocampus neuron dendrite receives input from two different sources, the side which is highly stimulated (100 Hz/sec) would produce the synaptic amplitude of the EPSP to be higher and lasts longer (memory). The other side of the dendrite will not be potentiated. This is a synaptic modification due to a correlated firing of cell A and B according to Hebb (Poo, 2011) and only the side of the dendrite that was related to the input get potentiated. The action potential will not occur at the other side of the dendrite where the input is not correlated to the neuron. Only connection between two specifically correlated neurons will be potentiated. LTP is further defined as an increase in the amplitude of the Excitatory Postsynaptic Potential and this leads to neurons in the hippocampus to exhibit long term potentiation (LTP), the cellular molecular basis for memory.

Long Term Potentiation (LTP) due to Associativity

One of the property of LTP is due to neuron's association with similar input. Poo (2011) explains that if we have two neurons one with a weaker input and another with a stronger input and if the one with a weaker input is stimulated the Excitatory Post Synaptic Potential (EPSP) or current, which is a measure of synaptic strength, an excitatory synapse will not be potentiated and therefore will not produce LTP. The synaptic amplitude of EPSP remains the same as can be seen in figure 4.

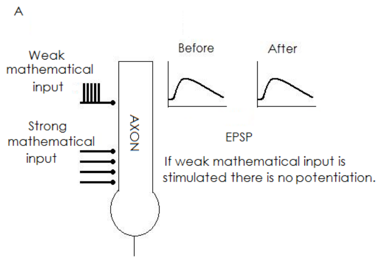

Figure 4: ***Excitation of weaker mathematical input does not affect EPSP***

If the stronger input is stimulated with a high frequency, the post synaptic cells activated will be able to potentiate and activate the LTP as shown in figure 5.

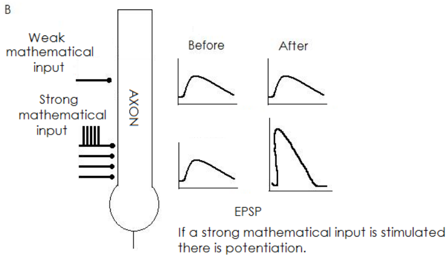

Figure 5: High frequency on a *Strong mathematics input stimulated an action potential - high EPSP*

However if the weak input is associated with the stronger input by administering a strong frequency at the same time the weak input is potentiated and the LTD is stimulated in both inputs and the synaptic amplitude of EPSP goes up in both inputs.

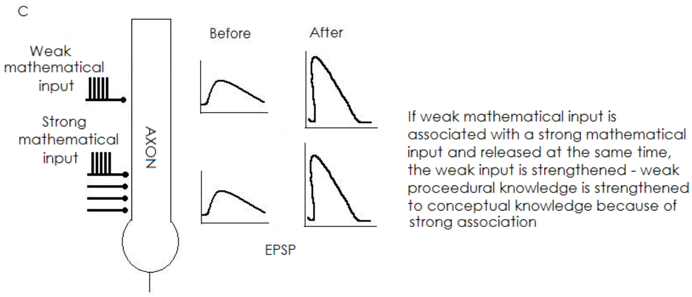

Figure 6: ***Weak mathematical input strengthened by correlated stimuli associated with stronger input***

The descriptions here are critical to mathematical explanations where associativity of mathematical concepts with other related concepts is critical to conceptual understanding. For instance when explaining mathematical concepts it makes sense to relate theorems in circle geometry to properties of a circle and it explains why lack of the latter leads to difficulties in conceptualising the former. These changes at molecular level are due to synaptic plasticity of the brain and allow for learning and memory.

THE ESSENCE OF INTERCONNECTIVITY OF INPUT - mathematical signal

Input such as a mathematical signal is strengthened when it is connected and relevant, hence when mathematics is being taught research (Stein at al 2006; Schoenfeld 2014) show that mathematical information should be related to what the learners know. Neurologically, synapses are strengthened by correlated activities (Cell that fire together wire together) and that perceptual memory of sensory experience involves the formation of a specific group of interconnected cells (Cell assembly) (Poo, 2011; Bear et al. 2001)). Mathematical input should therefore point to information that is related, topical and targeted at specific learning outcome. During mathematical explanations – input is targeted at a specific topic with examples, illustrations, class exercises and homework the learner develops strengthened LTP, the connections between the cells is strengthened and this is perceptual learning. There is therefore neurological evidence that understanding mathematics is a result of repeated association of concepts with previously learnt work or previous similar mathematical stimuli. Some synapses are strengthen and others are weakened by experience, the more the experiences/synapses the stronger the memory and learning.

In explaining the mathematical cognition, the input of mathematics concepts will activate specific areas of the cortex respond and stored in one area. This means that the reaction or the synaptic potentiation of neurons are specific to mathematical input and input on the other side of the same dendrite that is none mathematical such as history or language will not potentate the neuron. Only specific synapses that are mathematical will modify that area of the hippocampus – different sites for different inputs. Dehaene (2011) research on the concept of 'number sense' - the symbolic representation of quantity as an important foundation for mathematics and laying in specific areas of the cortex. Cantlon et al. (2006) used functional magnetic resonance imaging (fMRI), a neuroimaging technique, with adults and children to examine whether there is an early-developing neural basis for abstract numerical processing and area known as the intraparietal sulcus (IPS) was identified as corresponding to the processing of numbers.

Hussain (2012, p.8) expounds that the information relevant to educational psychologists is that some learners are characterised by specific difficulties understanding number concepts, lacking a sense of number and quantity, and have problems learning number facts and procedures, and such skills have been linked to the developing brain'. Critical here, especially to teachers at elementary school is that children's brains at this stage are still at their developmental stage and lack of effective mathematical cognition leads to dyscalculia. This is a condition that affects the ability to acquire arithmetical skills. Dyscalculia learners may have difficulty understanding simple number concepts, lack an intuitive grasp of numbers and have problems learning number facts and procedures (Hussain, 2012, p.8). Studies such as that of Wilson et al. (2001) have used current discoveries in neuroscience to develop computerised educational interventions for learners with dyscalculia. Hussain (2012) points out further that these studies used personalised instructions on the concept of number sense, for instance, to evaluate learners' performance and relate it to the difficulty of the tasks provided. Temple et al. (2003) asserts that mathematical stimuli that addresses learners' conceptual enhancement and mathematical performance have neural link and is shown by an increase in brain activity in areas that were originally under activated.

CONCLUSION

This paper provided the introductory neuroscience literature envisaged to be essential for mathematics teachers as well as provided neuronal explanations to what causes conceptual knowledge acquisition and how that can be reinforced. There is therefore neurological evidence that understanding mathematics is a result of repeated association of concepts with previously learnt work. In order for learner to understand and consolidate conceptualisation of mathematical concepts frequency of exposure to mathematical concepts has a better effect on memory than length of the exposure. Repetition through revision exercises, class work and homework and summary of covered content creates LTP because there is reinforcement of the synapses that allow the mathematical information to be retrieved. This type of knowledge is critical for teacher as it reinforces their knowledge of the essence of revision, prior knowledge and constant reinforcement of the instructions with innovative and cognitively appealing teaching aids, illustrations and information. Cognitive dissonance is created when teaching is boring, uncoordinated and superficial, the brain can block the information leading to un-potentiated signals and low or no memory of the mathematics being transmitted.

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