Learning three-dimensional Geometry and interaction of Brain Development.

Giannis Nikolopoulos[1,*], Viki Kanta[2], Louis Papageorgiou[2], Fragkiskos Chaniotis[2], Dimitrios Chaniotis[2,*]

[1]National and Kapodistrian University of Athens;
[2]Department of Biomedical Science, University of West Attica;
E-mail: inikolop@primedu.uoa.gr and dchaniotis@uniwa.gr

Abstract

The psycho-pedagogical theories must address their diachronic findings in the light of neurosciences. The conclusions of neurosciences in education need to be taken on board. The brain function explored by CT scan (through brain images), and functional magnetic resonance imaging by fMRI (through live imaging of human activities) have given rise to thoughts and answers for successful learning and furthermore about interaction in brain development. Neuroscience emerged as a branch of biology. However, nowadays it is an interdisciplinary field that mainly studies mental and emotional behaviors. It indicates solutions for better learning in both typical development children and in children with learning difficulties. Research has shown that spatial and mathematical abilities are closely related. The study of 3-D geometry e.g., the volume of solids, improves children's visuospatial working memory and reasoning training, and has as a result significant progress in mathematics education. Also at the same time, a significant effect is observed in the brain, especially in the hippocampus.

Keywords: Brain, Neuroscience, Geometry of Space.

Introduction

Over the last 20-30 years, the astounding progress of science, gave rise to several new concerns and provided some confirmed views on the functioning of the brain in relation to education. Researchers in educational neuroscience investigate the neural mechanisms of reading, numerical cognition, attention, and their difficulties including dyslexia, dyscalculia, and ADHD as they relate to education. "Education is about enhancing learning, and neuroscience is about understanding the mental processes which involved in learning. This common ground suggests a future in which educational practice can be transformed by science, just as medical practice was transformed by science" – Report by the Royal Society, UK (2011) [1].

1.1 The role of Neurosciences in Education

First, neurosciences, as a combination of two words, refer to the sciences that study the nervous system. However, neurosciences and education need to work together in the following areas: attention deficit, brain plasticity, and in memory (short-term and long-term). Goswami (2004) [2] argues that employing neurosciences facilitates our understanding of some basic perceptual, cognitive, and mnemonic aspects of cognition. According to Toscani (2016) [3], the goal of the collaboration of neurosciences with education is to create a common conceptual and methodological framework that would facilitate school systems wishing to integrate neurosciences into their practice. However, our primary preoccupation in the process of teaching and in the outcome of learning is to find the appropriate ways to transmit, recruit, transform *"information"* in the brain into knowledge and then convert stored knowledge, e.g., the *"data"* into something always usable.

We know that the brain is malleable (new neurons are constantly being created) and that we keep on learning throughout our lives; a successful teaching-learning partly depends on the appropriate method to attract the interest of all students and especially those with an attention deficit (it is evidenced that a 3% to 6% of students has an attention deficit and this is due to a central nervous system dysfunction). Quality and in-depth learning create strong mnemonic traces that contribute to the storage of knowledge as well as to recalling this knowledge when it is useful, as reported by Papadatos (2010: 143) [4]; Bennett (2010: 656) [5] & Toscani (2016) [3].

In the past, neuroscience was a branch of biology. However, nowadays in addition to biology, it draws on chemistry, computer science, genetics, medicine, engineering, linguistics, mathematics, physics, psychology. The revolution in neurosciences, which study the structure and function of the human brain, has direct implications in areas such as education, as they have shed light on the mechanisms of learning, attention, and memory. Neurosciences, on the other hand, explore the way in which the brain learns, that is, study the changes taking place at the level of brain structures during learning, as reported by Ansari & Coch (2006) [6]; Zafrana (2017) [7] & Papadatou-Pastou (2018: 125) [8].

1.1.1 The role of Attention Deficit

The view that a student is "frivolous and careless" has been studied and addressed by research on Attention Deficit. Today it is known that the brain does not give the appropriate command for concentration and focus throughout the entire teaching process. Rosenzweig et al. (2011: 792) [9] report that, the examination of healthy individuals confirms that, the prefrontal cortex is key in behavior directing a person towards a target. Even in animals, particularly in monkeys, the neurons of the prefrontal cortex become particularly activated when the animal must decide. This demonstrates that the prefrontal cortex controls the behavior for each targeted direction. Researchers have found a relation between low dopamine levels and Attention Deficit. Reduced dopamine in the brain is thought to be one of the causes of ADHD.

Bennett (2010) [6] notes that the key neurotransmitter playing a role in Attention Deficit Hyperactivity is dopamine. It is truly paradoxical that through amphetamine, these problems are treated [it is known that the introduction of amphetamine into the body increases alertness and activity]; the introduction of amphetamine is successful because it increases frontal activity, so the control of executive functions occurs So the increase in dopamine levels reduces or eliminates the symptoms of Attention Deficit Hyperactivity.

If we exclude issues that fall beyond the scope of this paper, such as the combined psychological and pharmaceutical intervention in students with Attention Deficit, it should be emphasized, as Bastea (2014) [10] observes, that the multisensory teaching method is useful for a prolonged attachment (focus) of students with or without Attention Deficit, as an indicative positive teaching.

1.1.2 Harnessing Brain Plasticity

As currently advocated by modern research, namely that the brain has plasticity, then many issues change in relation to learning. The traditional notion that *"the student fails in mathematics"* or *"geometry is for a few"* turns out to be incorrect and outdated. The idea that there are "good", "bad" or "mediocre" also "fast" and "slow" students is dismissed as observed by Kassotakis & Flouris (2013: 80) [11]. According to Tobrou (2013) [12], advances in research methods and techniques of new sophisticated forms of brain imaging, such as fMRI, have contributed to the investigation of the neurobiological basis of intelligence, as they accurately reveal aspects of brain structure and function.

The senses that participate in academic learning are Visual, Auditory and Tactile. In traditional teaching, the teacher of mathematics makes a verbal explanation to what students see on the chalkboard or marker board. In addition, the child may have tactile contact with both a cylinder or a cube, along with tactile activity when drawing with the pencil or with the chalk, e.g., shapes of levels or solids.

Vlachos (2020) [13] reports that, in a recent metanalysis, Planton, Jucla, Roux and Démonet (2013) co-evaluated the findings from eighteen neuroimaging studies, with the aim of identifying the brain regions that are usually activated during writing. Based on the metanalysis data, three areas of the brain are consistently activated in all writing activities. These areas are the parietal lobe, which includes the Broca region, and the prokinetic cortex in the dominant hemisphere which governs language function (the left, in the majority, of people), as well as the adversary (right) posterior cerebellum. Drawing on the findings of neuroscience, the act of writing affects and develops the brain's plasticity, and it is also presumed that there is a similar effect on the brain's plasticity when manually creating or designing shapes, in geometry 2-D or 3-D dimensions.

1.1.3 Memory and Learning

The senses accept the inputs of information. The information is entered, evaluated, and then led to full processing. There is a relationship between Memory and Learning, that is, the former as a short-term one, contributes to the learning process and then a strong, in-depth learning of a teaching object preserves the latter in the long-term memory. Polysensory teaching methods make use of multiple sensory channels of information entry into the brain, enhance memory first in the storage and then in the retrieval of information, as characteristically mentioned by Gabrieli (2009) [11] and Papadatos (2010) [14]. According to Ghazanfar, & Schroeder, 2006; Driver, & Noesselt, 2008, as well as Bastea (2019) [15], the human brain has evolved biologically, in such a way that it operates in natural environments, wherefrom it receives multiple stimuli flowing towards it, through many different sensory pathways. Findings of the researchers advocate that learning at all stages involves multisensory processes. Papadatos (2010: 343) [14] observes about memory, that the visual-spatial *"notebook"* in the short-term can hold more than one stimulus at a time and repeat information. The duration of information retention in long-term memory depends mainly on the strength of the mnemonic traces created during the learning phase. Rosenzweig et al. (2011: 726) [9] report that, even if it turns out that the person has learned something, it does not mean that it will be possible to recall it again in the future. The memory of this material may later be absent for a variety of reasons: it may never have been sufficiently formed, it may have weakened over time, it may temporarily not be able to be recalled due to the situation experienced by the person at that time. In the learning process, the knowledge deriving from neurosciences could be useful. In addition to brain plasticity and attention deficit, this knowledge could be used to create methods that facilitate memorization. Papadatou-Pastou (2018: 125) [8] points out that, a learning period is considered concentrated when the memorization of material runs in a short time, without the best results. On the contrary, the distributed learning period which is developed over time, i.e., it includes time gaps with the best learning results. And continues that the use of "TEST" as a strategy for more effective learning sounds like an oxymoron. "TESTS" are often considered a necessary evil to assess students. However, in this case this term is used to denote the method of retrieving information from long-term memory. Consequently, "TEST" can also take place during the study by the student himself. Consequently, in the next learning episode, it is possible to obtain better results precisely because these gaps will have been identified and can be studied in a targeted manner.

An additional useful factor for memorizing and understanding the concepts is their interconnection. For example, to depict on a paper the relationships between concepts, that can be connected and to create the so-called map of concepts (conceptual map). Several psychologists and educators who studied *"cognitive* *architecture"* on how memories of information, events and emotions are stored, concluded that concepts store elements in a network; the better memorizing and understanding of the concepts are formed through their frequent reappearance and interconnection in time as observed by Stefanidis (2006) [16, 17].

These findings lead to the conclusion that the neurosciences of education cannot be ignored in modern teaching. It should be noted that the above views, as emerged from several surveys, suggest didactic directions, such as the example with "TEST", away from the school environment through questions, which mathematics teachers can and should create on online platforms. It could be argued that neurosciences today address the issues of education; therefore, the theories by the psychologists-pedagogues Vygotsky, Piaget, and the pedagogue Pierre Van Hiele, formed several decades ago, are no longer useful nor consistent. Neuroscientific studies of the brain and its function could be used to disprove or validate psychological theories of learning. Educational practice uses psychological theories, developed over the past century or so, what if we had scientific evidence to illuminate which ones should be developed and which could be discarded? Toscani (2016) [3].

The utilization of neurosciences and the connection with psychopedagogical theories leads to better learning outcomes. This paper states that the two models, i.e., neuroscientific, and psychological do not oppose each other but are converging. On the one hand, we have biochemical explanations, and on the other hand we have the psychological ones. Biochemical models are usually considered as the antipode to psychological explanations. A more appropriate way of considering these two approaches is that they provide different levels of explanation. The psychology of development is part of the cognitive sciences and/or neurosciences. Relevant examples are provided through the psychology of education. The new 'Science of Mind' stemmed from the fusion of behavioral and cognitive psychology, neuroscience, and molecular biology. This new Science can answer questions that serious thinkers have struggled for millennia to answer, namely how the mind acquires knowledge, as reported by Lehalle & Mellier and Gutierrez (2014) states that neuroscientists and child psychologists inform us how the human brain stores verbal and graphic information in two different regions, and Vinner, S. (1991) claims, that verbal and graphic information is represented in positions in memory as different contexts: the graphic frame is called the concept image and the verbal context is called the concept definition [19].

Kandel (2008) [19] argues that, according to neuroscience, neuronal circuits related to perception form fixed synaptic connections, while neural circuits related to memory have synaptic connections that change power with learning. This mechanism is the basis of improvement of memory and higher mental functions.

1.1.4 Math Anxiety and Learning

It is worth exploring another dimension, the Mathematical Anxiety that affects memory and consequently learning. Mathematical Anxiety is associated with general anxiety; however, it is delimited in a specific fear of mathematics, and an almost permanent negative reaction and attitude towards mathematics and mathematical processes is generally observed. In fact, it encompasses a range of emotional reactions, from mild situations, such as anxiety or dislike to actual fear. Stress largely impacts on the educational process, since it distracts thinking, affecting memory capacity and thus reducing learning performance. This view is supported by research showing that students with high anxiety in mathematics have a poorer memory. However, it should be noted that, in addition to genetic and environmental factors, what is referred to as the stress of mathematics manifesting itself in students, can be attributed to teachers and to the way mathematics are taught, as reported by Vinson (2001), Ashcraft & Kirk, (2001), Ashcraft & Ridley (2005) and Nikolopoulos (2021) [20, 21, 22]. As per Lyons & Beilock, (2012) [24], recent research in the human brain has found that in the mathematical processes, Mathematical Anxiety seems to activate the areas of the brain associated with the management of negative emotions. This possibly explains why people with high levels of anxiety tend to avoid mathematics and as Nikolopoulos (2021) [21] observes that *the "Anxiety of Mathematics"* works inversely from the feelings of satisfaction and tranquility.

According to Papadatos (2010) [14], the science of 'mind' has discovered that "electromagnetic waves" in the brain are emitted at five different frequencies: 'δ' waves (1-4 Hz), 'θ' waves (4-8 Hz), 'α' waves (8-13 Hz), 'β' waves (13-30 Hz) and 'γ' waves (about 30-70 Hz). In this regard, the focus is on the "alpha" waves because only these are produced when the person is in a state of physical and mental relaxation. Research demonstrates that people display the highest level of learning and assimilation of information, when in the "alpha" state, when many brain regions are activated. In the educational process some students have learning difficulties and some others have gifted abilities. Neuroscience provides the answers to these discrepancies.

1.2 Brain, Intelligence and Emotion

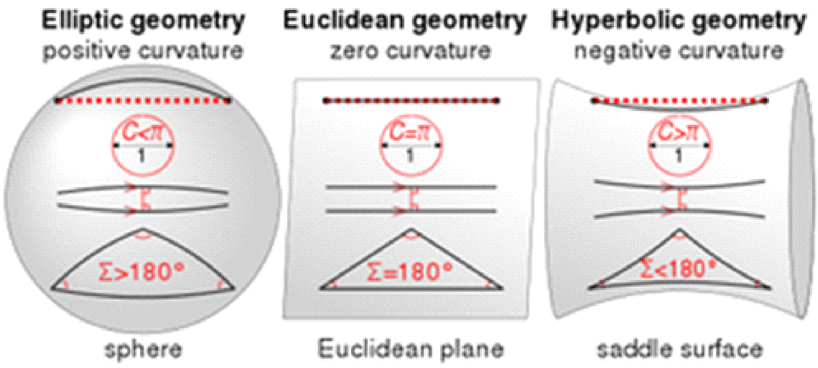
The brain is the most complex organ of the human body. As argued by Papadatos (2010) [14], the complexity of the brain, makes it capable of successfully performing all higher functions. These functions include intelligence, and emotion. Intelligence includes memory, learning, while emotion includes joy, sadness, anger and, more generally, a range of observable behaviors. The term emotion defines the mood of man, which is mainly caused by the impact of the environment. Emotions are divided into simple and complex. The "emotional" aspect of the human brain is only a part of its incredible dynamics and, by extension, the role it plays, in general and especially in human behavior. The source of emotions is objective reality, according to Smirnov et al. (1974) and Diamantopoulos, D. (2013) [25,26]. Giotakos (2018) points out that, emotions have the same function as they had in the past and their structure was shaped through the individual's constant effort to solve problems posed by the environment [27]. In addition, Giotakos (2021) [28] report that, the *cognitive theory of emotions* (Oatley, K.; Johnson-Laird, PN., 1987), argues that the main function of emotions is to coordinate the architecture of the brain modules and that the emotions enhance adaptation to the continuous environmental challenges and opportunities presented throughout the evolution of the species. According to this theory, the emotions are triggered when the person feels that the progress of his/her current goals is threatened or that it requires an adjustment. Simple emotions include joy, sadness, anger, fear, optimism, anxiety. What is of interest to this educational process is the fear or anxiety around mathematics. According to Bennett (2010), this fear or anxiety is a useful emotion, because in the absence of fear we would defy the dangers resulting in injury or even death. Therefore, fear serves an important benefit for the survival of our species [5]. Not with standing that we connect the two concepts, it is worth noting that anxiety and fear should not be considered as identical. Sovermezli (2019) observes that according to Spielberger (1982) and Lazarus (1991), fear and anxiety have a basic difference. The fear it relates to an emotional reaction, caused by a specific, objective risk [29]. As Nikolopoulos (2021), mentions, the anxiety of mathematics is defined as the insecurity that students feel about the subject of mathematics [21]. It is a condition and is related to the emotional functions of the brain. It usually stems from the negative experiences of students, regarding the subject of mathematics, either the inherent difficulties presented by the teaching object, or because of the responsibilities of the environment (teachers and parents). However, the fear/anxiety for mathematics affects mathematical performance, reducing it to a minimum.

1.3 Biological Bases of Behavior

The psychological "principles" for teaching and learning, attempting to bring in research from areas of psychology, are the following inter alia: developmental, educational, evolutionary, cognitive, social, and biological. Biological psychology, which is the most up to date, states the following: The transmission of information takes the form of an electrical impulse, i.e., an electrical signal. Neurons contain chemicals, to send messages. There are microcysts at the end of each neuron. When these microcysts are stimulated by the electrical impulses that are transported through they neuro-axon, then neurotransmitters are released, for example dopamine. Myelination also has a strong impact on behavior, since it strongly affects the speed of nervous impulse and, consequently, the chronological order of events within the nervous system. Note that, glial cells provide myelin and glial cells are added to the nervous system throughout the life of the human being, as suggested by Vosniadou (2001) and Rosenzweig et al. 2011 [9,30].

1.4 The Geometry of Space and the Brain Development

Roy & Llinas (2008) say that Pellionisz and Llina proposed a geometric interpretation for understanding brain function. The relationship between the brain and the external world is determined by the ability of the central nervous system (CNS) to construct an internal brain model of the external world using an interactive geometric relationship between sensory and motor expression [31]. According to Habas et al. (2020), reviving Pellionisz and Llinas general hypothesis regarding the cerebrum and the cerebellum as geometric machines, it is speculated that the cerebellum should be involved in implementing and/or selecting task-specific geometries for motor and cognitive skills [32]. Widdowson & Wang (2021) claim that people have extraordinary spatial abilities, which helps them navigate the world [33]. Also, research shows that the brain has the inherent abilities to perceive spatial geometry, even before it is taught. According to Golomb (2017), the results showed that as an image first enters our visual cortex, the brain mostly codes the two-dimensional location. But as the processing continues, the emphasis shifts to decoding the depth information as well. As we move to later and later visual areas, the representations care more and more about depth in addition to 2-D location. It's as if the representations are being gradually inflated from flat to three-dimension. The geometric perception is shown in the figure below, however, while the earth is spherical and the navigation takes place in curved space, however, man does not perceive it when moving in his office, in his orchard and generally in daily spatially limited activities, and this is how it "works" with Euclidean Geometry.



Widdowson & Wang (2021) observe, that spatial knowledge is central to how people perceive the physical world. Research suggests that spatial representations may conform to at least two mathematical systems: the Euclidean or the non-Euclidean [33]. The cognitive map is a neural model of the external spatial world which represents the distances and directions between places. Cognitive map representations are embodied by spatial-responsive cells found in the entorhinal-hippocampal neural circuit (Rolls & Kesner, 2006; Poulter et al., 2018). Grid cells in the medial entorhinal cortex (MEC) each encode multiple locations that collectively express a hexagonal grid pattern across the whole explored environment (Hafting et al., 2005; Killian et al., 2012).

The human brain thinks about space in different ways. It usually thinks of everyday short distances, however, in some of these ways it helps to judge the relative position of things at very long distances, e.g., if Paris is east of London and west of Rome. Judd & Klingberg report (2021), spatial and mathematical abilities are strongly associated [34]. We analysed data from 17,648 children, aged 6–8 years, who performed 7 weeks of mathematical training together with assigned spatial cognitive training with tasks demanding more spatial manipulation (mental rotation or tangram), maintenance of spatial information (a visuospatial working memory task) or spatial, non-verbal reasoning. We found that the type of cognitive training children performed had a significant impact on mathematical learning, with training of visuospatial working memory and reasoning being the most effective. This large, community-based study shows that spatial cognitive training can result in transfer to academic abilities, and that reasoning ability and maintenance of spatial information is relevant for mathematics learning in children.

As mentioned, through neuroscientific research, the development of knowledge emerging in recent decades, shows that our brain has a tremendous ability to grow and change at any stage of life. Some of the most surprising figures came from studies by taxi drivers in London. People in London are only allowed to own and drive these iconic cars if they successfully undergo extensive and complex spatial training, learning all the roads within a 20-mile radius of Charing Cross, in central London, and every connection between them. At the end of the training, they give them a test called "gnosi". Neuroscientists decided to study the brains of taxi drivers and found that spatial training caused a significant increase the area of the hippocampus. This region is important for many reasons. First, studies conducted on adults of different ages, showed significant brain development. Secondly, this specific area of the brain - the hippocampus - is important for all forms of spatial and mathematical thinking, as observed by Woollett & Maguire (2011) [35]. As Pulter et. al. (2018) present, common elements found in mammalian spatial mapping systems, focusing on the cells in the hippocampal formation representing orientational and locational spatial information's [36].

1.5 The Brain, the Geometry, and the movement

According to Berthoz (1999) [37], the combination, in humans, of methods of experimental Psychology, of brain imagery by fMRI, and in animals of fine methods of neuronal recordings, has allowed us to reveal the neural mechanisms of the control of gaze. We have also explored the neural basis of spatial memory and spatial disorientation such as observed in psychiatric symptoms as agoraphobia. In particular we have shown the role of the limbic system and of parieto-frontal systems in these processes. These results open new avenues in Neurology for the understanding of symptoms such as spatial neglect or topographic memory or perturbation in the control of posture and locomotion.

The new element we are trying to present is the change of the very traditional view with which one deals with classical Euclidean geometry. A geometrical figure corresponding to a geometrical problem should not be considered as a physical entity in a state of rest and immobility, but as a dynamic pulsating system whose various elements relate to each other without disturbing the harmony and internal coherence. It is precisely this ability to move and change some elements on a defined basis that determines the new interdependencies between these elements that ultimately balance in a unit this part is nothing but the proposed problem to solve. The position that "geometry is movement" where we seek to emphasize the basic principle of dealing with the geometric problem as formulated by Toumasis 2004 and Moisiadis & Dortsios, 2015 [23,38]. Our model suggests that the experience-dependent interactions between the entorhinal cortex and the hippocampus play a critical role in setting up the globally coherent firing maps in the entorhinal cortex. Grid cells indeed are able to provide a universal spatial metric for mammalian spatial navigation in complex environments, after familiarization of the environment claim [12].

Conclusions

The role of education in the children's development and the economical development of the nations is central. Suboptimal cognition has major long-term consequences for individuals and societies. Grantham-McGregor et al. 2007 [39], estimated that more than 200 million children in developing countries fail to reach their cognitive potential due to many factors. Children with suboptimal cognition are less likely to lead productive adult lives due to fewer years of schooling and less learning per school year. However, if there are no other negative social factors, we must study the conclusions of neuroscience. Thus, in the educational process some students have learning difficulties and some others gifted abilities. Neuroscience provides the answers to these discrepancies. Quoting (Stern, 2005; Willingham & Lloyd, 2007 & Vlachos, 2010), as well as Haliou et al. 2015 [40] attempts to link the findings of neuroscientific research with pedagogical theory and educational practice have a history of about thirty years. In recent years, an increased interest in the relationship between neuroscience and education has appeared, as shown by the multitude of articles that have been published in scientific journals and present evidence-based opinions on how these disciplines are correlated.

It is not possible today to claim that the Neuroscience of Education has given clear answers to outline the learning future of student, as teachers, educators, and parents look for. Therefore, it is important for neuroscientists and educators to work together to collaborate on today's knowledge base, jointly embarking on the effort to translate scientific findings into teaching or pedagogic skills. Toscani (2016) claims, that the new field or joint research called "Neuroscience of Education" is essential for the future of schools around the world [3,41].

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