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Contributions of Cognitive Neuroscience on Mathematical Learning as a Tool for Elementary School Teachers

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Abstract

The relationship between cognitive neuroscience and the area of education has been extensively studied in recent years. With technology, also comes the opportunity to know more about the brain and thus, how it reacts in the learning process. Mathematics is an area in which many students have great difficulty, so the present work seeks to present contributions that cognitive neuroscience brings to assist the teacher in the teaching-learning process, recognizing that studies involving these areas are increasing. Through a literature review, this article focuses on the teacher of elementary school, understanding that this educator is responsible for the knowledge base that will accompany the student during his school and academic life. Many educators are unaware of how the brain works and learns, they do not know the tools that can help them in their daily school life so that they can achieve a successful teaching-learning relationship. The main objective is to bring studies about the relationship between cognitive neuroscience, learning, and mathematics, considering that being aware of these studies leads to tools that can be used in the classroom. The results showed the importance of relating aspects of cognitive neuroscience with proposals for didactic innovation related to mathematical learning, to allow a new scenario that fosters new cognitive skills, especially in the Mathematics discipline.

Keywords: Cognitive neuroscience, learning, mathematics, elementary school.

1. Introduction

It is known by researchers and teachers that there are several factors that intervene in the current difficulty presented by most Brazilian students in Mathematics. It is common, according to Rocha Junior (2020), Mathematics learning to be treated as a very difficult content to learn, causing negative feelings and incapacity in students, defining as “the smartest” the one who can perform activities and understand what is proposed in this area, so those who do not understand math activities are seen in the opposite way.

Cognitive neuroscience appears, according to Consenza and Guerra (2011), as a successful partner of school learning because, currently, we can say that the brain and its manifestations are largely responsible for learning. There are several technologies and studies, predominantly international, that try to relate the areas, recognizing that they are complementary to each other. When we look at the Brazilian curriculum of undergraduate courses that train teachers, we do not observe any subject related to cognitive neuroscience, so it is noted that understanding some subjects about the brain can be relevant to the practice of educator. Several factors can be cited that together add up to reasons for the current denial of Mathematics learning present in schools, but it is important to be aware that they can begin to be solved from scientific studies and practices of teachers in the classroom.

In this sense, elementary school Teachers play an extremely important role in the child's life because they appear at the beginning of their school life, and consequently are responsible for presenting the basis of contents that become more complex over the years. In Brazil, the period from the 1st to the 5th school year includes an introduction of students to deeper knowledge that will be used in their daily lives and also in the continuation of the school period.

Indeed, from the point of view of Teixeira (2015), there is a certain difficulty in keeping the child's attention in the classroom, especially when they are younger. However, nowadays it is no longer up to the educator to take a more traditional role insisting that the child sits and listens, insisting on bringing so much content, in wanting to be heard and unfortunately not listening. It is necessary to recognize that children are in their process of growth and maturation, having needs related to the brain and body (CONSENZA; GUERRA, 2011).

Thus, this research aims to bring a bibliographic review about the relationship between cognitive neuroscience, learning, and mathematics, resulting in tools that this relationship can provide.

2. Report of the relationship between cognitive neuroscience and learning

A neuroscientific view on education appears in 1998, through studies realized by Byrnes and Fox (DE SMEDT; VERSCHAFFEL, 2010 apud. TOLEDO; LOPES, 2020). From the suggestion made by the authors, the production of research on the subject begins, which has grown more assiduously internationally during the last ten years. This suggestion was to focus studies on the brain for education (TOLEDO; LOPES, 2020).

Bartoszeck (2006, p. 3) says that "Neuroscience investigates the process of how the brain learns and remembers, from the molecular and cellular level to the cortical areas". Knowing that it is through the brain that we are able to become aware of the information we receive and process it (CONSENZA; GUERRA, 2011), understanding the functioning of the brain is essential and complementary to teaching practice (CARVALHO, 2010). Therefore, it is curious that, even though the brain is responsible for learning, educators know little about it and its functionalities (MOURA-SILVA, 2020).

Consenza and Guerra (2011) argue that learning about brain functioning can be very efficient in educator work. The authors also explain that it is possible for neurobiological and pedagogical issues to be related, as long as they are based on and guided by scientific evidence, also stressing that this relationship is reciprocal in both areas, as cognitive neuroscience also needs to enjoy the practice and difficulties of the classroom. However, the authors propose that it is necessary to include "[...] topics related to neurosciences in the initial training of the educator [...]" (CONSENZA; GUERRA, 2011 p. 145, *our translation*).

Mechanical models and formula repetition are widely included in basic education today, with a priority focus on mass memorization. However, depending on how they are carried out, they lead to delay in teaching students, because little information will be retained and for a short time (JÚNIOR, 2020).

In turn, Teixeira (2015) pays attention to the functioning of memory, specifically working memory, explaining that children with 5 to 14 age can pay attention to 3 or 4 information during a period that varies between 5 and 10 minutes. Thus, it is necessary that when teaching Mathematics the teacher uses little information at a time and includes small intervals of time in his classes, in addition to taking into account the "teaching Mathematics step by step" (TEIXEIRA, 2015 p. 15).

It can be said that no student is incapable of learning Mathematics. The educator can, to facilitate this process, appropriate different teaching strategies that result in the necessary skills and abilities for their students. (ARAÚJO; MENEZES; BEZERRA, 2019). To move in this direction, the teacher can "offer learning situations based on experiences rich in stimuli and promote intellectual activities [...]" (CARVALHO, 2010, p. 541, *our translation*).

3. Cognitive Neuroscience and Mathematics Learning

Human learning does not happen simply because the information is entered into our brain, it happens because this information is processed and interacted with each other (CARVALHO, 2010). According to Consenza and Guerra (2011, p. 11, *our translation*) "The brain is the most important part of the nervous system and acts in the interaction of the organism with the external environment, in addition to coordinating its internal functions". Therefore, it can be said that the brain is the organ responsible for learning, which modifies the brain structure of the learner. Pedagogical strategies and experiences acquired by the individual are responsible for this change, which also results in new behaviors. We learn when we acquire the competence to perform tasks and solve problems, that is when we become able to change our practices and the world around us using these new behaviors (CONSENZA; GUERRA, 2011). And it is in this sense that Bartozesck (2006, p. 2, *our translation*) asserts that "[...] learning is the process by which the brain reacts to environmental stimuli, activating synapses, making them more intense".

With the technology we have today, it is possible to use image mapping techniques, providing the opportunity to analyze the brain anatomy and visualize how the brain works when it performs some action (CARVALHO, 2010). Based on this information, we can highlight that the relationship between cognitive neuroscience and learning can generate positive results since it is through the brain that this phenomenon happens and with the use of current technology we are given the opportunity to understand and intervene when necessary. Knowing the brain, we can know its processes and, among them, learning, which helps the Mathematics teacher to use a more realistic approach (ARAÚJO; MENEZES; BEZERRA, 2019).

Teixeira (2015, p. 15) states that "mathematics is the science of patterns" and explains that this is a broad concept and has an endless search for "an order and a structure". The author also states that this aspect should be taken into account in the teaching and learning of Mathematics since the brain is a great pattern detector. Thus, the author discusses the importance of developing the sense of number, starting from what is innate, identifying it as an essential part of success in learning Mathematics.

However, referring to documents that mention Mathematics in the school curriculum, we can mention the BNCC (Base Nacional Comum Curricular) which draws attention to the fact that, in Elementary School, the application of the subject has to seek resources beyond the "four operations" despite being extremely important focuses. And explaining a little of its definition, the document also cites that "Mathematics creates abstract systems, which organize and interrelate phenomena of space, movement, shapes, and numbers, associated or not with phenomena of the physical world" (BRASIL, 2018, p. 265, *our translation*).

Human beings are born with the ability to distinguish two to three – or even three to four – objects. Knowing this, we can say that a baby, innately, already has a sense of number, even if it is simple. Studies point out that this fact has an evolutionary explanation because when man went out to hunt he was able to, by analyzing the number of animals he observed, identify whether that situation was a hunting opportunity or in danger. There are speculations that our ancestors also relied on their fingers in their first contacts with arithmetic and thus, it appears that using this mechanism in childhood at the beginning of school life is natural (TEIXEIRA, 2015).

Knowing that human beings already process the concept of quantity early, Consenza and Guerra (2011, p. 112, *our translation*) state that contact with mathematics education develops "[...] recognition of numbers, their verbal expression, as well as the procedures for performing multi-digit calculations, for example". Thus, it is necessary for children to exercise these skills so that their brain functioning takes place in an integral way, allowing the formation and consolidation of nervous connections. Biologically speaking, mathematics does not manifest itself in a single place in our brain, there are several regions that contribute to this processing. Our culture, with the passing of the school years, contributes to our nervous circuits adapting and modifying, and these, through stimuli, start to work being in contact with circuits that deal with the notion of quantity (CONSENZA; GUERRA, 2011).

There are phenomena that interfere with the successful teaching of children. Among these phenomena, there is a worldwide Mathematics culture that does not value the teaching of Mathematics itself. This culture is composed of feelings of exclusion, disinterest, and, many times, rejection of the subject. Mathematics is often considered "difficult" and "for few people", sometimes even being responsible for the feeling of incapacity, which ends up corroborating the non-favoring of the learning of the subject and the low performance of the students. The psychologist João dos Santos Carmo (2014 apud. ROCHA JÚNIOR, 2020) discusses a new type of anxiety, naming anxiety to Mathematics. This anxiety is responsible for all reactions (physiological, cognitive, and behavioral) of the individual in situations that involve both the teaching of Mathematics at school and the use of this science in everyday life, arising from the experience of the individual and being fortified by society and family. Thus, we present here one of the reasons for which an emotional valuation in schools is due, being "one of the justifications for the failure in mathematics seen in many Brazilian schools" (ROCHA JÚNIOR, 2020 p. 12).

Consenza and Guerra (2011) emphasize that from a neurobiological point of view, learning occurs when the connection between nerve cells is formed and consolidated. This learning follows the process of the nervous system of each one, based on chemical and structural changes, consuming time and energy for its manifestation. As educators, we can facilitate the learning process, but it is important to take into account that it is an individual manifestation that obeys the uniqueness of the historical context of each individual. They explain that when we turn our gaze to this historical context, we can cite factors that collaborate for learning to take place. Thus, we cannot help but talk about attention, memory, and emotion.

Attention, according to the authors, is the phenomenon that allows us to focus on one stimulus among all the others that affect us, that is, to pay attention to what we emphasize to be important at the moment and to let go of what we call needless. Memory, on the other hand, includes several subdivisions, being a non-unitary phenomenon where it is processed through specific neural systems. These systems make the memory composed of particular types of processing that are stored in a fragmentary way, ie, different information is stored in different systems that are located in different regions of the brain.

No less important than attention, emotion internally identifies when some important information is happening and then, when captured, it becomes a focus of attention and becomes conscious. Upon becoming conscious, it is directed to the cerebral amygdala which controls emotions and motivational processes. Therefore, motivation is a phenomenon that is linked to a circuit responsible for regulating behaviors that satisfy needs (feeding or reproduction) and results in the systematization that operates data from the internal environment such as hunger, pain, sexual desire, and the external environment such as opportunities and threats, defining the behavior that is showed (CONSENZA; GUERRA, 2011).

When the teacher has the opportunity to study how the brain learns and its relationship with learning, he can apply the use of motivation in the classroom (also noting its importance) and still understand his students' learning processes, achieving helping them to work even more on their capacities (CARVALHO, 2010). Araújo, Menezes, and Bezerra (2019) also explain that to help the low performance of students in Mathematics

> [...] it is necessary to work on the teacher yours scientific knowledge, as well as to obtain knowledge through neurosciences in partnership with neuroeducation, especially about knowing the student and the importance of identifying the knowledge input behavior of each one, and the group relationship (ARAÚJO; MENEZES; BEZERRA, 2019, p. 6, *our translation*).

All students are fully capable of learning Mathematics. According to Boaler (2018) there are no such things as "mathematical talent" or "mathematical brain", even children with special needs have the same condition of brain growth and change, in other words, the author comments that "new evidence from neuroscience reveals that everyone, with the right message and teaching, can succeed in math, and everyone can achieve high levels of learning in school" (BOALER, 2018 p. 4, *our translation*).

4. Cognitive Neuroscience Tools for Elementay Education Teachers

The BNCC emphasizes that children in Elementary Education have characteristics that bring the need for an organization in school work that turns its attention to "[...] the interests manifested by children, from their most immediate experiences [...]" (BRASIL, 2018 p. 58, *our translation*). Thus, they have the possibility of expanding their knowledge, mobilizing cognitive operations that will consequently become more complex, and allowing themselves to feel the sensitivity of the world, to learn, express and act on it (BRASIL, 2018).

Studies show that addressing situations that the student already knows and providing opportunities for him to relate information he has already seen with the new information presented is a positive practice for learning, this happens because by doing so the teacher allows the neural networks of students to expand (TOLEDO; LOPES, 2020). Teixeira (2015) states that studies prove that information that has some effect and brings meaning to the student is more likely to be stored in his memory. Memory is widely used in school, but in a mechanical way, which does not help students to acquire new knowledge, this all results in the difficulty of students in solving mathematical questions (JÚNIOR, 2020). On the other hand, knowing the memory and the studies that point out its functioning, the teacher can have a very different answer. It can be said that attention and working memory need to be considered when solving mathematical problems, which will also help to stimulate the circuits that are involved in these phenomena. When we talk about memory in general, for information to remain fixed in our brain, additional work needs to occur, focusing on processes of repetition, elaboration, and consolidation, remembering that all processes must have meaning and sense for the student. In addition, investing not only in verbal processing but in auditory, tactile, visual, or olfactory processing is very important and useful, as more than one access channel to the brain is used, helping memory and its establishment (CONSENZA; GUERRA, 2011).

It can be said that the brain has its own motivation to learn, but it needs to recognize information as important. Therefore, one way to get the attention of students is to present the content in a way that they can see the importance of it. Therefore, asking questions about the importance of learning that content and how to present it in the best way so that students can see this importance can help the teacher. Link the contents presented with what the student already knows, carry out activities centered on the students, use interactivity, present and supervise goals that they must achieve, reduce elements that can be distracting in the classroom, and make didactic resources more flexible with good humor or music and not presenting extensive expositions in a way that continually distracts the attention of the students, are some examples that can also help the teacher (CONSENZA; GUERRA, 2011).

We already know that the teacher, adopting his role as a mediator, is a fundamental part of the learning of children. Júnior (2020, p. 4, *our translation*) explains that the content, the didactics, the teaching method that the educator will use "must be carefully selected/constructed, in order that the construction of knowledge to be carried out is not incomplete and questionable". And to complement Bertozesck (2006) states that:

> Successful teaching by changing the rate of synaptic connection affects brain function. Of course, this also depends on the nature of the curriculum, the capacity of the teacher, the teaching method, the context of the classroom, family, and community (BARTOZESCK, 2006, p. 3, *our translation*).

This all entails an aspect that must also be taken into account: the teacher-student relationship and error. Toledo and Lopes (2020) highlight that a good relationship between educator and student will determine the attention the student will pay to the explanations of teachers, directly interfering with the student's chances of learning. Thus, studies about the error prove that the reaction of the teacher to the error presented by the student is a phenomenon that is directly related to learning (JÚNIOR, 2020).

The error, according to Consenza and Guerra (2011) proposes to the student moments that he can reflect on and even allows him to seek new ways to solve it, which can be a way to make learning more efficient. Silva and Romão (2022) when seeing the error of students, comment that the teacher does not take into account the student's reasoning when reaching that result, only paying attention to the one who faithfully followed his way of reasoning, reinforcing the idea of Banking Education proposed by Freire. Still, the authors point out that by not following exactly what was proposed by the teacher in a resolution, students are led to wrong resolution and discredited for thinking of different solutions.

When talking about emotion, Consenza and Guerra (2011) turn their attention to motivation and its relationship with learning. This relationship is presented by the fact that motivation leads us to repeat actions that generate rewards and, with that in mind, we can look for situations in the future that bring us to the same (or similar) feeling of pleasure, that releases dopamine and that leads to learning. Also, according to the authors, emotions "are a central phenomenon of our existence and we know that they have a great influence on learning and memory" (CONSENZA; GUERRA, 2011 p. 83, *our translation*). Knowing this, they also emphasize that it is necessary to value emotions within the school, that is, the classroom must be designed to integrate positive emotions such as enthusiasm, creativity, and involvement and to avoid negative emotions such as demotivation, anxiety, fear, and frustration, being necessary to take into account moments of relaxation in the school environment (CONSENZA; GUERRA, 2011).

Finally, Bertoszeck (2006) brought a modified table where he cites practical examples of the relationship between cognitive neuroscience and the classroom.

Table 1. Cognitive neuroscience principles with potential application in the classroom

Cognitive neuroscience principles	Classroom
1. Learning and memory emotions become intertwined when activated by the learning process.	Learning is a social activity, and soon the students need opportunities to discuss topics. A peaceful environment encourages students to express their feelings and ideas.
2. The brain gradually changes physiologically and structurally as a result of experience.	Practical classes/physical exercises with the active involvement of participants make associations between previous experiences and current understanding.
3. The brain shows optimal periods (sensitive periods) for certain types of learning, which do not end even in adulthood.	Adjustments of expectations and performance standards to the specific age characteristics of students, use of integrative thematic units.
4. The brain shows neuronal plasticity (synaptogenesis), but greater synaptic density does not predict greater generalized ability to learn.	Students need to feel "owners" of activities and topics that are relevant to their lives. Pre-selected activities with the possibility of choosing the tasks increase the responsibility of students in their learning.
5. Several areas of the cerebral cortex are simultaneously activated in the course of a new learning experience.	Situations that reflect the real-life context, so that new information is "anchored" to previous understanding.
6. The brain was evolutionarily designed to perceive and generate patterns when testing hypotheses.	Promote situations in which attempts and approximations are accepted when generating hypotheses and presenting evidence. Use of case solving and simulations.
7. Due to its primitive heritage, the brain responds to pictures, images, and symbols.	Provide occasions for students to express knowledge through the visual arts, music, and drama.

Source: BARTOSZECK (2006, p. 4, *our translation*).

5. Conclusions

Through bibliographic reading, it is clear that something has already allowed us to observe nuances of new pedagogical alternatives, bringing the possibility of learning and, with that, helping to complement daily practices as an educator. We know that learning takes place through the brain and learning about it and its manifestations around this phenomenon is extremely necessary to understand the neurological processes that occur during the learning of children.

Mathematics is one of the subjects that present a lower performance and a greater disinterest on the part of students (ROCHA JÚNIOR; 2020), this is due to the fact of a series of factors that involve culture and didactics. The culture, according to Rocha Junior (2020), because many believe that they were not born to understand mathematics and still replicate the idea that mathematics is extremely difficult to learn and, furthermore, that only a select group of intelligent people is able to understand it, and solve exercises on the topic persists today. With regard to didactics, according to Rocha Júnior (2020), it is due to the fact that school mathematics is first learned in an educational institution, and the first contact that the individual will have with the discipline will be at school, everything that the individual will develop emotionally will define his relationship with mathematics.

In this sense, the debate invites the area of cognitive neuroscience as a didactic alternative to update the techniques used by traditional teaching methods, whose expected objective is for students to develop not only in Mathematics but in all curricular subjects. Practices that are recurrent in the performance of teachers, if modified, can present promising results, such as making the error something to be used in the classroom, trying to understand what the student thought at the time of the error or if he simply solved it in a different way. Emotions, attention, and memory, neurologically speaking, are factors that we must also take into account so that we are not subjects who insist on just replicating and not listening to what students have to say.

However, the relationship between cognitive neuroscience and education has been growing, and international research on the subject continues to appear (CONSENZA; GUERRA, 2011). Thus, inserting a study on cognitive neuroscience and how the brain learns in teacher training can help for a possible change in the way many educators see learning and children.

A significant amount of research and studies have already been carried out, treading a path to results closer to the desired ones when considering the reduction of school failure and dropout rates. Articulating the scientific evidence of cognitive neuroscience, new didactic proposals for education, and considerations about mathematical learning, allows us to imagine an avant-garde scenario that, over time and, who knows, through the effort of researchers, teachers, and students to discover new cognitive skills and that it is possible to learn, considering that learning is subject to the homeostasis of the Central Nervous System, which expects to process stimuli compatible with its ability to perceive the reality in its surroundings

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