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# The Mathematical Brain, Neuro-Didactic Strategies to Learn Mathematics

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## ABSTRACT

This descriptive research paper analyzes the neuro-didactic strategies employed by both teachers and students in the process of learning and teaching mathematics. The teacher's perspective focuses on the act of teaching, while the student's perspective revolves around the act of learning. Strategies are derived from insights into learning and development drawn from neuroscience and the brain's capacity for learning, incorporating four learning theories—Guildford, Thurstone, Gardner, and Stanislas—which intertwine to shape the mathematical brain. Moreover, the theories are elucidated, and strategies for problem-solving and teaching are extracted to enhance the effectiveness of learning in students' minds.

**Keywords:** strategies, neuroscience, brain, logical-mathematical

## INTRODUCTION

Nowadays, there is much talk about learning mathematics and how difficult it is for students to understand it, likewise of the deficiencies that they present in their grades or entrance exams for different Universities. Also, university or higher education centers have noticed that students arrive with little or no skills in mathematics, thus causing frustrations and failures in the academic areas to which they aspire. Similarly, it is observed that a series of factors do not allow the development of effective learning in mathematics and that students cannot understand its structure and how it is constructed.

One of the great difficulties in learning mathematics is developing abstract analytical thinking and scientific reasoning in the student. Orrantia (2006) points out that children begin to show specific difficulties in counting and separating numbers in arithmetic processes from their primary grades. Also, Fernandez (2013) states that Learning Difficulties in Mathematics can be one of the causes of school failure and, sometimes, can lead to the isolation of students in their educational environment and even to school dropout. She stresses that the teacher must know the causes and characteristics of these difficulties to treat them appropriately.

It is essential to highlight, therefore, the critical role played by the teacher's training to deal with these difficulties, but also their implication in responding to the attention to diversity; for this reason, we have tried to know the methodology used by some teachers in the teaching of Mathematics, as well as their training, concerns, and expectations regarding these difficulties. The teacher must know the student's aptitudes concerning Mathematics and their beliefs and attitudes toward this area of knowledge since they may hinder the learning of the subject. Similarly, Gonzalez *et al.* (2003) state that failure in mathematics is due to students seeing it as a complex subject from the beginning and failing to assimilate it as necessary and pertinent to their lives. They point out that failure is not a cause for concern since most students fail in this challenging subject.

One of the concerns is accentuated when the educational system accepts student failures in mathematics as something that occurs frequently and in large proportions, as it is a class few students master. For this reason, Castillo (2013) urged the search for non-conformist alternatives in mathematics learning and criticized that the systems accept failures as everyday situations with no remedy, or little can be done to improve. Similarly, Santiago, Maroto, and Palacios conducted a multivariate evolutionary study of attitudes toward mathematics in 2004, showing that students reject mathematics for various reasons. Among them are how the teacher teaches it, the learning is not meaningful to them, they do not see the subject as something pertinent, and it does not create challenges for them. In addition, they find it very frustrating that they do not understand the subject and are disconnected from its enriching understanding and analysis. Finally, they discovered that mathematics could produce episodes of frustration that affect the emotional process of students to the point that they reject professional areas that involve mathematics in their academic sequences.

Similarly, when countries measure their students with standardized tests, they notice a low achievement in mathematics. They often want to improve these deficiencies by training their teachers through workshops and professional improvement classes in teaching students. Nevertheless, what do we do with the student to enhance their understanding and comprehension of mathematics? Are we satisfied with training the academic staff, and what happens to the student's brain?

## WHY DOESN'T THE CHILD LEARN MATHEMATICS? ARE WE UTILIZING THEIR BRAIN TO FACILITATE TEACHING?

The idea of conformism in training teachers in new strategies or methodologies in mathematics is not enough. These must be accompanied by understanding the student's brain functioning to comprehend and understand the subject. Dehane (2016) points out, *"It is quite strange to see that many children dislike mathematics, but if we look at the youngest children, they are very intuitive. We have seen circuits in the brain that deal with numbers, space, or geometry that are present in early childhood. I think the mistake in school is teaching children that mathematics is very abstract and complicated. If we base mathematics on intuitions already in the child's brain, we could help them enjoy it."*

Similarly, Ansari (2016) pointed out that every teacher must understand how a child learns mathematics and how a mathematical brain is created in its analysis and reasoning. This greatly differs from the normal brain or standard way of thinking. The child's mathematical brain reacts to an understanding in a fractional, step-by-step manner in analyzing a problem. It also resorts to thinking about what it knows and brings with it to apply it to the mathematical problem before it. Thus, the structured teaching process implemented by the teacher in the classroom is expected to use the child's brain as the primary tool for their learning. This should be done through a multiplicity of pedagogical strategies that provoke and invite constant reflection and diminish the mechanistic process of solving problems in mathematics.

The teacher must use good mathematical language and the accuracy of definitions and concepts to go to mathematical algorithms. Similarly, the application must be constant in every process that occurs during the teaching of mathematics.

## PROBLEM STATEMENT

In the initial phase, it could be pointed out that learning mathematics is a global problem and that because it is so, we hopelessly accept it. But new research and findings show that how the teacher lectures the subject has much to do with this learning. Suppose the teacher is aware of the way and how the child learns. The pseudo-scientific scenario reflects that the child's brain is ready to learn from birth and must constantly be stimulated. Mora (2021) states that the child's brain is prepared to learn from birth and is waiting to be nurtured with emotion, surprise, intrigue, questioning, and creativity, where the child is forced to use his understanding and desire to learn and memorize what he has known to make it his own at any time.

Likewise, the scores obtained by students in standardized tests worldwide are described as a significant problem in mathematics learning. For example, in Puerto Rico, for the year 2018-2019, in the area of mathematics, students obtained the following scores: 14% of the students were at an advanced level, 16% were proficient, 50% were at a basic level, and 19%

were at the lowest level, which is deficient or pre-basic. This implies that almost 70% of the student population has not mastered the basic skills in mathematics. Similarly, in his study conducted by Diaz (2021), it was determined that in the United States, the level of achievement in mathematics is less than 23%. This is reflected in the PISA tests of 2020. Consequently, concern arises about the education system and its emphasis on mathematics learning. It points out in the PISA test report conducted in 2019 that the United States has been dropping a shallow position in the area of mathematics and science. It also states that this also has to do to a large extent with the investment of money made to teach this subject. For this reason, it is essential to propose a new way of teaching and learning mathematics starting from the child's brain and its different learning processes.

## THE THEORETICAL FRAMEWORK OF NEUROSCIENTIFIC INTELLIGENCE AND ITS APPLICATION TO MATHEMATICS

The theory establishes that there is a natural source of learning in the brain of every child. Correspondingly, Carrasco (2015) states that for total learning to occur in the child's brain, the two hemispheres, the left hemisphere (logical-mathematical) and the right hemisphere (artistic and creative) must be integrated, in this way the student would complete his learning and the teacher must use repetition, active memorization, emotion, movement, creation, enthusiasm, nutrition, the arts and respect the personal understanding of each child.

Marchicado (2015) points out that neuro-didactic strategies focus on the construction of meanings, the permanent interaction with other students, the analysis of concepts and contextualized cases, the approach to problems, the application of the content in the real world, the creation of new solutions and the promotion of systemic and speculative thinking from adequate management of emotions. Boscan (2011) proposed a typology to identify neuro-didactic strategies and organized them into *operational, socio-emotional,* and *methodological*. Operational strategies represent the set of creative stimuli planned by the teacher to present the content and respond to the student's interest and the characteristics of the educational context. Socio-emotional strategies involve emotional components that establish teacher-student and student-student bonds. These strategies allow the strengthening of commitment to learning and active experience. Methodological strategies are composed of procedures that promote inquiry, analysis, and construction of knowledge through logical processes and with the support of operational and socio- emotional strategies.

We will look at four theories that help us understand the type of intelligence each student has and how the teacher should approach their instruction for better mathematics learning.

### Guilford's Theory of Intelligence

Guilford's model is based on considering intelligence as the process by which the human being transforms information from the environment into mental content, so he has an operational view of it. The author establishes three separate and independent dimensions based on perception, information transformation, and response emission.

Specifically, he speaks of input elements or contents, operations, and output elements or products. Therefore, his model is three-dimensional and usually represented as a cube in which the interactions between the three significant dimensions interrelate to form up to 120 different factors. It is a taxonomic model that considers the different capacities as non-hierarchical, the different aptitudes being independent. Intelligence is thus a set of different aptitudes that allow us to adapt to our environment.

### Thurstone's Theory of Intelligence

Thurstone's (1947) aptitude model is based on seven aptitudes the learner should have to measure his intelligence. The aptitudes are the following: verbal comprehension, verbal fluency, numerical comprehension, spatial aptitude, mechanical memory, perspective speed, induction, or general reasoning. These capacities and aptitudes are the ones that the learner must have so that his intelligence is globalized, and he can understand and solve any mathematical situation, which is the one we will study in this case.

### Gardner's Theory of Intelligence

Gardner defines intelligence as the "ability to solve problems or produce valuable products in one or more cultures." Thus, first, he broadens the field of intelligence and recognizes what was known intuitively, that some kinds of intelligence are related to academic performance, but that others are not, no less important. He does not unify the concept of intelligence. However, he divides it into eight intelligences, some developing more than others, depending on the learner's abilities. These are linguistic, spatial, logical-mathematical, musical, bodily, intrapersonal, interpersonal, and naturalistic intelligence.

### Stanislas Dehaene's Theory of Intelligence

Stanislas Dehaene recently raised the need for the teacher, in addition to being the first to know the dynamics in the classroom, to acquire specific knowledge about how our brain works because, in his own words, "no one should know better than they do the laws of thought in full development, the principles of attention and memory." He divides the concepts of intelligence into a memory that absorbs and that the repetitive capacity of the brain in its neuronal function makes it a source and force for learning.

## NEURO-DIDACTIC STRATEGIES FOR LEARNING MATHEMATICS

### Memory

One of the significant challenges for the mathematics teacher is that nowadays, students do not want to memorize. This is due to the constant rejection received by people who confused what constructivism pointed out with memorizing. They understood memorizing concepts was terrible for the student's learning and confused it with a behavioral vision of information storage. On the contrary, memory is one of the capacities and levels of thinking the student is first asked to internalize since he will reach the analysis and the total development of creativity in his brain with it. Therefore, the student must memorize definitions, properties, mathematical laws, rules of algorithms, and everything that does him good to solve mathematical exercises. Mora (2021) points out that memory in the student is the fundamental basis where good learning begins. Then with this, significant levels of thought are developed until reaching one of the highest levels, such as creativity.

In mathematics, the child has to rely heavily on definitions, properties, rules, and algorithms that are in his memory to solve mathematical problems. Even more so if they are application exercises that are often given in the form of writing verbal issues. Carlota and Benavides (2020) point out that learning and memory are two linked brain processes that originate adaptive changes in behavior. Moreover, the stability of the neuronal changes after learning allows the consolidation of memory and its long-term maintenance.

Suppose the student has actively memorized the definitions and properties. In that case, the procedure for analyzing and solving a mathematical problem or exercise will come to his mind like lightning.

### Beautiful Lettering: The Art of Writing Numbers

As in any language that is learned, doing the numbers in a correct and organized way helps significantly in understanding. For this reason, when a child learns to write and read, they are oriented so that their handwriting is perfect, and anyone can understand. Likewise, the organization gives them a procedural style of thinking that aids in understanding analytical situations that arise. By worrying about how we write our handwriting and how we artistically write numbers, we focus on a careful analysis of what we do and how we do it. This dramatically helps the student internalize the ability to take care, reason, and analyze the mathematical problem they are solving.

**Playful Skills**

Games or skills to motivate thinking through challenges are a tremendous neuro-educational strategy. For example, when the teacher places several groups and gives a problem to see which group solves it first. Also, when he sets up different strategies, the group that develops the best one wins the challenge. In this way, the student will enjoy the learning process and acquire a love for mathematics. He will no longer see it as a science he cannot understand, which has only been made for some students with a magic brain for learning.

**Teaching with Passion**

One of the most significant motivating elements is the passion with which we teach things. A teacher who emphasizes his subject can infect his students with the same passion and provoke a great love for the subject. The art of the great orator is to insert a great power into his talk as if it were the last talk or lecture he will ever give. In this way, the student will be able to see that mathematics is exciting and adopt an awareness that they have to learn it to develop a tremendous analytical capacity in their mathematical brain. To motivate individuals and make them aware of their remarkable learning abilities, it is crucial to shift their mindset and provide strong mental support. It is more effective to approach challenges with the belief that one is capable of solving them rather than resigning to the idea of never being able to accomplish them. This is a significant challenge faced by both experienced teachers and the new generation of educators who embark on a journey toward the teaching process. According to Dominguez-Lara and Campos-Uscanga (2017), academic satisfaction encompasses psychological well-being (comparison between what was obtained and the initial pretensions) and enjoyment during educational experiences, which is intimately linked to the permanence and graduation rate of students as well as to academic success. Teaching with passion, motivation, vocation, and love creates and gives students the magical illusion of the enjoyment of learning.

**Application of Movement Practice**

Regular physical activity (mainly aerobic exercise) promotes neuroplasticity and neurogenesis in the hippocampus, facilitating long-term memory and more efficient learning, which significantly helps students be more alert to concepts and better learn the rules and procedures for solving mathematical exercises.

For a student to remain solidly still in a classroom was often perceived as being in total concentration. However, recent research indicates that where there is a classroom with thought activity, movement, interaction with laboratories, and concrete application practices, it has been noted that long-term memory is much more significant. The student can more efficiently acquire learning. It is recommended to create activities that involve movement and dynamic action. For example, suppose the concept of distance is explained. In that case, an activity can be created where students have to move at different distances. You can also make physical comparisons about time, speed, and distance. The idea is that the student's brain is always active and stimulated to create a long-term memory that is effective in learning.

**Mathematical Conversations (Mathematization)**

One of the students' most used and feared resources is verbal problems. However, the most significant difficulty lies in translating the oral problem into the mathematical equation to be solved. Although there are several methodological algorithms to guide us in solving verbal problems, one of the difficulties is understanding the mathematical language to perform the mathematization and to be able to solve the problem. This requires conversing mathematically and analyzing what they are asking from the point of view of science. This is when the child must enter the verbal problem as the main protagonist of the problem. Verbal problems must be adjusted to the age and understanding of the student so that they can understand and identify themselves with them. This requires they be allowed to make mistakes and begin a new analysis starting from the error, leading to a deeper analysis of what is to be found in the problem, what I want to solve, and what tools I have for it. But in the same way that a student needs correct vocabulary in the language to carry out his essays, so does the student need it to solve verbal problems. Guillen (2022) points out that retrieving prior knowledge from memory, connecting it to new experiences, and mentally rehearsing what could be done differently next time leads to more active learning. Retrieval practice is more potent than other techniques commonly used by teachers and students, such as lecturing, rereading, or note-taking.

**Mathematical Representations and Models (Use of Technology for the Brain)**

Technology is among the most powerful tools for teaching mathematics. Nowadays, numerous applications are available to students, enabling them to visualize and analyze the procedures of each mathematical problem. The only mistake is that technology is often used merely for the application to solve the problem and replace the brain’s understanding and analytical reasoning. This is where the role of the excellent teacher comes into play, who, with the help of technology, will help the student find properties, theorems, applications, rules, and patterns in each mathematical skill to be mastered. Through the questions of counterexamples and guided reasoning through mathematical maieutics, technology will be effective and of great help to learn and understand mathematics.

**Calmness: Patience in Teaching and Procedures (Step-by-Step)**

An essential virtue that every mathematics teacher must possess is the ability to teach procedures and topics with calmness, as well as the patience to wait for students to acquire them. The student’s brain needs a calm period to absorb what is being taught. Then, it must be ready for learning, retention, acquisition, and application. Three primary stages constitute learning: encoding, consolidation, and retrieval (Nadel *et al.*, 2012). Encoding is the process by which we acquire information through the sensory stimuli that reach us from the outside. Consolidation allows us to store information, that is, to transform short-term memories into long-term memories. Furthermore, retrieval occurs when we remember something we previously learned. We tend to think that most learning occurs during the encoding stage. However, learning is strengthened during retrieval. Therefore, extracting information from the learners’ minds is more effective, rather than filling them with data. In this process, the teacher assumes the role of a principal author, emphasizing the practicality of patience to ensure effective learning. Understanding that students engage in sound reasoning, thorough analysis, and successful application prepares their brains for optimal learning outcomes. For the following, Agarwal *et al.* (2021) point out that asking students to retrieve information is an effective learning method. It is more than just a review; it involves creating an environment of analysis and reasoning. Within this environment, students utilize the information they have retained and expand upon it, solidifying their understanding through mental recall of mathematical knowledge.

**Ask to Make, Create, and Build on the Student's side**

Creativity represents one of the highest forms of human thinking, and as such, it should be consistently encouraged by teachers within the classroom. Similarly, when assigning work and projects outside of school, there should be an emphasis on fostering creativity and the application of mathematical concepts. Encouraging students to apply creativity in solving mathematical problems is highly beneficial. Likewise, in fostering mathematical growth, solving problems within mathematical competitions that promote creativity and require analytical thinking at an advanced level is highly productive. When such a level of thinking is encouraged, it is important for teachers to understand that mistakes will occur, as pointed out by Ekuatio (2020), embracing mistakes becomes crucial if we aim for mathematics to be a creative subject, as making mistakes is inevitable and essential for discovering new insights.

The history of civilization shows that we only create things when we can make mistakes. Many of the greatest inventions and discoveries directly resulted from things going wrong. For example, Penicillin was discovered when unwanted bacteria blew into a Petri dish. The Post-It note was the brilliant adaptation of a glue that was not sticky enough to work as glue. It is in this way fostering creativity that the world's great works, projects, and solutions have been discovered. Likewise, Araya *et al.* (2019) state that creativity helps teachers foster the teaching structure with open-ended questions and mathematical models that develop their analytical skills to unimaginable levels.

## CONCLUSIONS

The presentation and application of the four theories of intelligence to logical-mathematical thinking offer a range of ideas that encourage teachers to further engage students' mathematical brains from the perspective of educational neuroscience. New research on human intelligence has influenced teaching methodologies across disciplines, particularly in the realm of thinking and problem-solving in mathematics. However, considering the prevalence of technology today, which readily provides algorithms for problem-solving in mathematics, students may miss opportunities to develop their own problem-solving skills and engage their brains in the process.

We have introduced neuro-didactic strategies for teachers to integrate into their classroom teaching process, aiming to enhance the effectiveness and support students in learning mathematics from early grades to advanced and university levels.

While we have focused on the contributions of four theorists in understanding thinking development from a neuroscience perspective and how the brain learns, it is now the responsibility of each teacher to implement these neuro-didactic strategies to strengthen and facilitate the teaching and learning of mathematics.

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