NEUROPEDAGOGICAL ASPECTS OF MATHEMATICS TEACHING IN THE PRIMARY STAGE (GRADES 1-4)

Galya Kozhuharova
Trakia University, Bulgaria, galya.kozhuharova@trakia-uni.bg
Yana Nikolova
Trakia University, Bulgaria, terra74@abv.bg

Abstract: The aim of this article is to provide a theoretical synthesis of key findings from cognitive neuroscience that reveal the fundamental mechanisms of mathematical learning in primary school children (grades 1-4). The article aims to build a bridge between fundamental brain science and everyday pedagogical practice by proposing scientifically based approaches to overcome common difficulties and negative attitudes towards mathematics. The methodology used is a systematic review and analysis of interdisciplinary scientific literature, covering publications from the fields of cognitive neuroscience, developmental psychology, educational neuroscience and mathematics education pedagogy. The focus is on the "translation" of neuroscientific principles into the language of pedagogy in order to develop effective and brain-based teaching strategies. The results of the analysis identify three main neurocognitive pillars of mathematical learning. The first is the innate "number sense" (Approximate Number System - ANS), localized in the intraparietal sulcus, and the critical transition from this intuitive foundation to the abstract symbolic system of formal mathematics. The second pillar is the central role of cognitive functions such as working memory, which acts as a "mental workspace" for solving multi-step problems, and visual-spatial thinking, which underlies the understanding of geometry and number lines. The third pillar is the modulating effect of emotions. It has been found that mathematical anxiety activates the amygdala and blocks cognitive resources, while a positive and engaging environment stimulates the dopamine reward system, which facilitates learning and memory. In conclusion, it is stated that mathematical competence is not a given in advance, but is a developmental process that is highly dependent on the correspondence between pedagogical methods and the natural mechanisms of the brain. Success in mathematics is built on the construction of a strong neurocognitive foundation, not on the mechanical learning of procedures. Based on these conclusions, several recommendations are formulated. It is necessary to integrate basic knowledge of educational neuroscience into teacher training so that they can understand "why" certain methods are effective. Mathematics curricula should be revised, emphasizing the deep development of number sense, flexible thinking and the construction of a positive mathematical identity in each student. Strengthening collaboration between neuroscientists, psychologists and educators is encouraged to conduct more applied research in real classrooms. The article concludes by presenting a framework of specific, scientifically based neuropedagogical strategies for practical application in the classroom, including creating an emotionally safe environment, using multisensory approaches and managing cognitive load.
Keywords: neuropedagogy, mathematics education, elementary stage, cognitive neuroscience, working memory

1. INTRODUCTION

In recent decades, a new interdisciplinary field has emerged – neuropedagogy – which aims to build a bridge between the discoveries of neuroscience and educational practice. (Barabanova & Kazlauskiene, 2020). This convergence offers an unprecedented opportunity to rethink and optimize pedagogical approaches. One of the biggest and most persistent problems in education is mathematics education, where many students develop anxiety, negative attitudes, and feelings of incompetence at an early stage (Boaler, 2015; Davronbek, 2023). These difficulties are often not due to a lack of ability in children, but to a fundamental mismatch between traditional teaching methods and the natural ways in which the human brain learns and processes quantitative information.

Neuropedagogy is based on neurodidactics – its practical application, which focuses on the development of teaching methods, strategies and tools that are adapted to the functioning of the brain (Arnold, 2009; Ferreira & Rodríguez, 2022). A key postulate of neurodidactics is that learning is a biological process that leads to physical changes in the brain (neuroplasticity) and is inextricably linked to emotional states and motivation (Goswami, 2006; Howard-Jones, 2012; Mora, 2013). When the learning environment is perceived as threatening or stressful, cognitive resources are diverted, which hinders learning. Conversely, positive emotions and engagement stimulate the brain's reward centers, facilitating memorization and comprehension (Sánchez & Hincapié, 2024).

This "pedagogical mismatch" is particularly evident in mathematics. The human brain has an innate, evolutionarily constructed ability to intuitively perceive and compare quantities, known as the Approximate Number System (Approximate Number System (ANS) or "number sense" (Dehaene, 1992; Weisberg, 2008; Wynn, 1992). This system is primarily visual-spatial and nonverbal. The challenge for primary education is to help children connect this

intuitive foundation with the abstract, symbolic system of formal mathematics (Arabic numerals, arithmetic signs) (Wynn, 1992). Traditional teaching often skips this critical "grounding" step by directly introducing abstract symbols and procedures that are disconnected from the child's concrete experience (Boaler, 2015). This leads to cognitive overload, misunderstanding, and frustration, which gives rise to the widespread perception that mathematics is "hard" and accessible only to a few (Boaler, 2015).
The objectives of this article are:

1. To synthesize key findings from cognitive neuroscience regarding the fundamental mechanisms of mathematical learning in children in grades 1-4.
2. To analyze the critical role of cognitive functions such as number sense and working memory, as well as the modulating effect of emotions on the learning process.
3. To derive and present a framework of scientifically based, neuropedagogical strategies for teaching mathematics at the elementary level.

2. MATERIALS AND METHODS

The methodology used in this article is a systematic review and theoretical synthesis of interdisciplinary scientific literature. The study covers publications from several key areas: cognitive neuroscience, developmental psychology, educational neuroscience (neuroeducation), and pedagogy of early mathematics education.
The analysis focuses on identifying converging data and findings that reveal the neurocognitive underpinnings of mathematical knowledge and skills acquisition. The primary goal of this approach is to "translate" fundamental neuroscientific principles into the language of pedagogical practice, thereby laying the foundation for developing effective and brain-friendly instructional strategies (Goswami, 2006; Howard - Jones, 2012). This method justifies presenting the following sections as results and discussions of the synthesized scientific evidence and its practical applications.

3. RESULTS: NEUROCOGNITIVE FOUNDATIONS OF MATHEMATICAL LEARNING

The synthesis of scientific literature reveals three main neurocognitive pillars that underlie successful mathematical development in elementary school age.

3.1. The innate "feel for numbers" and the transition to symbolic mathematics

One of the most significant discoveries of cognitive neuroscience is the existence of an innate "number sense" (number sense) (Dehaene, 1992). This is a fundamental, nonverbal ability to estimate and compare quantities, which is observed in humans from a very early age and even in other animal species. The neural substrate of this ability is located primarily in the intraparietal sulcus (IPS) – a region in the parietal lobe of the cerebral cortex (Dehaene, 1992). This intuitive system, also called the Approximate Number System (ANS), serves as the conceptual foundation upon which formal mathematical knowledge is built (Dehaene, 1992).
A critical developmental task in elementary education is to build a strong connection between abstract symbols (e.g., the number "5") and the internal sense of quantity (five objects) (Wynn, 1992). The brain processes symbolic and non-symbolic quantitative information in different neural pathways, and mathematical competence depends on their effective integration (Dehaene, 1992). Effective teaching must purposefully facilitate this process of "mapping" by using visual, tactile, and kinesthetic methods to make the abstract concrete and understandable (Boaler, 2015).
Furthermore, research has shown that the brain uses different neural networks for different types of mathematical tasks. Retrieving arithmetic facts from memory (e.g., the multiplication table) relies heavily on verbal-auditory circuits, located primarily in the left angular gyrus . This makes rote learning and repetition (learning) a neurologically justified strategy for automating these specific facts. At the same time, tasks requiring procedural understanding and manipulation of quantities (e.g., subtraction by crossing or word problem solving) activate visuospatial networks in the parietal lobes (Dehaene, 1992). This distinction suggests that a one-size-fits-all pedagogical approach is ineffective; methods should be differentiated according to the specific cognitive process they aim to develop.

3.2. The central role of working memory and visual-spatial thinking

Working memory is the cognitive system responsible for temporarily holding and mentally manipulating information needed to perform complex tasks. It functions as a "mental workspace" or "mental board." In mathematics, its role is crucial: it allows a student to remember intermediate results when solving a multi-step problem, to keep in mind the conditions of a word problem while choosing a strategy, or to perform mental calculations. The capacity of working memory is limited, especially in young children. When a task requires too many mental operations at once, working memory becomes overloaded, leading to errors and dropouts.
The brain's visuospatial network is equally fundamental to mathematical thinking. It underlies abilities such as constructing a "mental number line," understanding geometric shapes and their transformations, visualizing parts of

a whole (fractions), and recognizing patterns (Dehaene, 1992). Activities such as building with blocks, drawing diagrams, using an abacus, and even counting on your fingers directly engage and strengthen these neural circuits, thereby laying the foundation for more abstract mathematical thinking (Boaler, 2015).

3.3. The Emotional Brain: Anxiety vs. Engagement

Emotions are not the enemy of rational thinking, but an integral component of it that can either help or hinder it. Math anxiety is a real physiological reaction, not just a "bad attitude." Situations perceived as threatening (e.g., a test, fear of making a public mistake) activate the amygdala, the fear center in the brain. This activation can "hijack" cognitive resources from the prefrontal cortex, which is responsible for logical thinking, planning, and working memory. As a result, the student literally cannot think clearly, which leads to poor performance and reinforces the belief "I'm not good at math" – a self-fulfilling cycle (Davronbek, 2023; Mora, 2013).

In contrast, a positive, supportive, and intellectually stimulating learning environment promotes the release of neurotransmitters such as dopamine . Dopamine is key to motivation, attention, and memory consolidation (Howard -Jones, 2012). Activities that are novel, playful, challenging, yet achievable, and that provide a sense of progress and success activate this reward system. This makes the learning process enjoyable and leads to the formation of stronger and more lasting neural connections (Howard - Jones, 2012; Sánchez & Hincapié, 2024).

4. DISCUSSION: FROM NEUROSCIENTIFIC PRINCIPLES TO CLASSROOM PRACTICE

Understanding the neurocognitive foundations of mathematical learning requires a shift from traditional to brain-based pedagogical practices. This section presents three main strategic directions that directly arise from the results presented above.

4.1. Strategy 1: Cultivating a brain-friendly, emotionally safe environment

The first and most important step is to create a classroom where the fear of making mistakes is minimized. This means actively changing the culture in the classroom, reframing mistakes from a sign of failure to a valuable opportunity for learning and "brain growth." This approach is the basis of the concept of a "growth mindset. " mindset) and is directly related to the principle of neuroplasticity (Boaler, 2015). Teachers can apply specific techniques such as "My Favorite Mistake", in which an anonymous mistake is analyzed by the whole class to understand the logic behind it. It is also necessary to encourage and praise the process – the effort made, the strategies tried, the persistence shown, and not just the final correct answer (Boaler, 2015; Sánchez & Hincapié, 2024). In this way, the activity of the amygdala is reduced and the capacity of the prefrontal cortex is freed up for full learning.

4.2. Strategy 2: Prioritizing number sense through embodied and visual-spatial learning

To build a strong connection between intuitive number sense (ANS) and formal mathematics, learning must begin with the concrete and the sensory. This requires extensive use of:

- **Manipulative materials:** cubes, balls, sticks that allow children to "touch" and "see" quantities and operations with them (Boaler, 2015).
- **Visual models:** number axes, diagrams, schemes that help organize thinking and make abstract connections visible (Boaler, 2015).
- **Embodied knowledge cognition:** using the body as a learning tool – counting on fingers (which is neurologically related to the development of mathematical skills), representing geometric shapes with the body, games with movement in space (Boaler, 2015).

The goal is to make mathematics "understandable, useful, and beautiful" by connecting it to the real world, telling it through stories, and discovering its aesthetic patterns (Boaler, 2015). This strengthens the connection between concrete quantities and abstract symbols, giving them meaning.

4.3. Strategy 3: Engaging Multiple Memory Systems and Adjusting for Cognitive Load

Effective teaching must take into account both the different memory systems and the limitations of working memory.

- **Gamification (Game-Based Learning (GBL):** Games and educational technologies are extremely powerful neuropedagogical tools. They activate the dopamine reward system, which increases motivation, engagement, and concentration (Howard -Jones, 2012). Games provide immediate feedback, create a safe environment for practice without fear of mistakes, and can be adapted to the individual pace of each student (Howard -Jones, 2012; Sánchez & Hincapié, 2024).
- **Cognitive load management: Teachers need to be aware of the limited capacity of working memory. This means "** chunking " complex tasks into smaller, manageable steps , teaching clear and explicit strategies, and providing external supports such as written instructions or graphic organizers. It is necessary to balance the introduction of new concepts with sufficient practice to automate the skills and move them

from working to long-term memory (Arnold, 2009).

- **Differentiated exercises:** Based on the discovery of different neural pathways, practice should be varied. Retrieval practice is effective for automating facts (e.g. addition to 20, multiplication tables) through short tests and spaced repetition (For developing flexibility in problem solving, interleaved practice is more suitable), in which different types of tasks are alternated (Arnold, 2009).

The following table summarizes the relationship between neuropedagogical principles and specific classroom practices.

Table 1: From neuroscientific principle to classroom practice

Neuropedagogical principle	Key brain mechanism	Sample classroom strategy	Supporting sources
Emotional safety improves learning	Reduced amygdala activation; increased prefrontal cortex function for logic and working memory.	Reframe mistakes as learning opportunities; praise the process and effort, not just the answers.	(Boaler, 2015; Mora, 2013; Sánchez & Hincapié, 2024)
The brain learns through patterns and connections	Hebbian learning ("neurons that fire together, wire together"); strengthening of synaptic connections through associations.	Connecting new concepts to prior knowledge; using real-world analogies and storytelling.	(Boaler, 2015; Howard - Jones, 2012)
Learning is multisensory and embodied	Engaging the visual, motor, and somatosensory cortex creates stronger and more redundant neural pathways for retrieving information.	Using physical manipulative materials, finger counting, drawing tasks, kinesthetic activities (e.g., geometry with a body).	(Boaler, 2015)
Play and novelty stimulate attention and memory	Release of dopamine in the brain's reward centers, which increases motivation and consolidates memory.	Application of gamification (GBL), puzzles and new, non-standard problem-solving scenarios.	(Howard-Jones, 2012; Sánchez & Hincapié, 2024)
Working memory has limited capacity.	The prefrontal cortex can only hold and manipulate a small number of elements at a time.	Breaking down multi-step tasks into smaller parts; teaching clear strategies; using visual supports and graphic organizers.	

Source: Authors' research

Statistics and observations about teachers in Bulgaria

There is an insufficient number of mathematics teachers in Bulgaria, and the teaching profession itself is showing trends of an aging profession. There is an alarming shortage of mathematics teachers in the country - only about 4,406 out of a total of 92,000 teachers teach the exact science. Teachers under 30 are only 7.5%, which is significantly lower than the European average / Bgonair Chernomore /. One third of teachers are over 55 years old, according to data from the National Statistical Institute at the end of 2024. There are difficulties in retaining young specialists in the profession. As many as 80% of young teachers leave the profession during the first academic term or a few months after starting Telegraph.bg . Data from another source indicate that over 70% of young teachers leave in the first year, with the average age of the teaching staff reaching 54 years Chernomore .

A number of studies show that 80% of teachers suffer from burnout dariknews.bg . In the field of digitalization, 72% of teachers do not use artificial intelligence in their work, and 41% have never applied it, which indicates poor digital training of teaching staff BNR Economy .

These statistics clearly show that there is an urgent need to attract and retain young teachers, because without fresh staff, reforms in the training process will hardly be sustainable. The aging of the staff and the high rate of burnout emphasize the need for better working conditions, psychological support and opportunities for professional development. We believe that targeted work with teachers is necessary to implement technological and brain-based methods in the classroom, based on neuropedagogical science.

5. CONCLUSION

The analysis of neuropedagogical aspects of early mathematics education reveals that mathematical competence is not an innate gift, but a developmental process, strongly dependent on the correspondence between pedagogical methods and the natural mechanisms of brain functioning. Success in mathematics is built on strong neurocognitive foundations, including an intuitive sense for numbers, effective functioning of working memory, and the maintenance of a positive emotional environment that promotes engagement and reduces anxiety.

The findings of this article have important practical implications. A shift in teacher training is needed, incorporating a basic knowledge of educational neuroscience that allows them to understand "why" certain methods work better than others (Ferreira & Rodríguez, 2022). Mathematics curricula need to be revised, shifting the emphasis from the mechanical learning of procedures to the deep development of number sense, flexible thinking, and the construction of a positive mathematical identity in each student.

Future research should focus on strengthening collaboration between neuroscientists, psychologists, and educators. Conducting more applied research in real classrooms is crucial to validating and fine-tuning brain-based teaching strategies, which will contribute to creating more effective, equitable, and motivating mathematics education for all children (Dehaene, 1992; Goswami, 2006).

LITERATURE

Arnold, M. (2009). *Brain-based learning and teaching . With a focus him/her the 7th grade* . VDM Verlag .

Barabanova, I., & Kazlauskiene, A. (2020). Neuropedagogy : preconditions for application of neuroscience results in the education process while providing feedback . *Technium Social Science Journal , 2* , 112-122.

Boaler, J. (2015). *Mathematical mindsets : Unleashing students ' potential through creative math , inspiring messages and innovative teaching* . Jossey -Bass.

Davronbek, Y. (2023). System of Principles of Neuropedagogy . *The European Journal of Education , 4* , 126.

Dehaene, S. (1992). Varieties of numerical abilities . *Cognition , 44* (1-2), 1-42.

Ferreira, D.D.M., & Rodríguez, T.P. (2022). Brain-based learning : A systematic review of the literature . *Sistemas , Cibernética e Informática , 19* (1), 40-46.

Goswami, U. (2006). Neuroscience and education : from research this practice ? *Nature Reviews Neuroscience , 7* (5), 406-413.

Howard -Jones, PA (2012). Neuroscience and education : A review of the contribution of brain science this teaching and learning . *The Curriculum Journal , 23* (2), 169-191.

Mora, F. (2013). *Neuroeducación : solo yes can learn that that yes ama* . Alliance Editorial .

Sánchez, D.A.M., & Hincapié , D.A.Z. (2024). Integrating Neuroscience into Mathematics Education through Game-Based Learning : A Study with Pre -Service Teachers . *Education Sciences , 14* (3), 213.

Weisberg, D.S., Keil, F.C., Goodstein , J., Rawson , E., & Gray , J.R. (2008). The seductive allure of neuroscience explanations . *Journal of Cognitive Neuroscience , 20* (3), 470-477.

Wynn, K. (1992). Addition and subtraction by human infants . *Nature , 358* (6389), 749-750.