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Mental Arithmetic and Its Impact on the Development of Mathematical Abilities

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Abstract: This article examines the influence of mental arithmetic on the development of mathematical abilities. This domain represents a fundamental cognitive function that underpins mathematical thinking. Over the past decades, interest in this issue has significantly increased due to advancements in neuroscience, psychology, and educational technologies. However, despite extensive research, unresolved questions remain regarding the neural mechanisms underlying mental calculations, the impact of external factors on arithmetic performance, and the effectiveness of various training methods. The objective of this study is to systematize contemporary scientific perspectives on mental arithmetic and its effects on the development of mathematical abilities. A review of the literature reveals that researchers employ a wide range of approaches, from neuroimaging techniques to cognitive experiments focused on the role of auditory and visual stimuli. Nonetheless, scientific debates persist concerning the neuropsychological models of mental arithmetic, its interaction with working memory, and attentional processes. It is concluded that mental arithmetic is a complex, multifaceted process influenced by both individual characteristics and external conditions. The author's contribution lies in proposing a conceptual framework for understanding the impact of mental arithmetic on the development of mathematical abilities. These findings will be of interest to psychologists, neuroscientists, educators, and developers of mathematical training programs.

Keywords: cognitive processes, mathematical abilities, mental arithmetic, neuroscience, numerical cognition, cognitive training.

Introduction: In the current educational landscape, there is a noticeable and systematic shift from traditional teaching methods to practices that enhance cognitive development. Given the increasing focus on cognitive development and the search for new approaches to teaching mathematics, mental arithmetic serves not only as a subject of theoretical analysis but also as a significant practical tool.

The importance of this topic lies in the need to reconsider the mechanisms of computational skill formation within the framework of specific cognitive training. The core issue addressed in this study is how the development of mental calculation processes contributes to structuring mathematical thinking and optimizing working memory and attention.

In line with this, contemporary researchers aim to develop models that connect mental arithmetic practice with neurocognitive mechanisms and abstract problem-solving strategies. Their work is based on experimental training, neuropsychological testing, and an analysis of cognitive performance dynamics.

MATERIALS AND METHODS

Research on mental arithmetic can be categorized into several groups based on methodological approaches.

The first category focuses on analyzing brain activity during arithmetic operations using various neuroimaging techniques. In the study by F.A. Farahani et al. [3], functional near-infrared spectroscopy (fNIRS) with continuous wavelet transformation was used to identify patterns characteristic of mental calculations. A similar approach, emphasizing signal complexity, was applied by A. Ghouse et al. [4] in analyzing the relationship between mental arithmetic and motor imagery. D. Ma et al. [8] employed a modified multiparametric complexity metric to recognize brain states during calculations. Using electroencephalography (EEG), K. Kim et al. [6] examined microstates in the brain depending on the success of arithmetic operations, while S. Dattola [2] used electromyography to map active brain regions.

The second category of studies examines the impact of external and cognitive factors on the effectiveness of mental calculations. F. Kattner et al. [5] investigated the influence of background auditory stimuli on accuracy and processing speed in arithmetic tasks, identifying the mechanism of auditory distraction. W. Ross et al. [9] analyzed the role of external numerical representations in children's mental calculations, demonstrating that interactive number manipulation improves computational accuracy. S. Salvaggio et al. [10] focused on the predictive function of eye movements during arithmetic operations, suggesting that visual scanning strategies correlate with mathematical performance. W. Ross et al. [11] explored how manipulating external numerical representations affects children's success in mental arithmetic. L. Dawei et al. [12] described an experimental study aimed at improving elementary students' mental arithmetic abilities through a structured learning approach.

The third category of research is dedicated to developing educational methodologies that enhance arithmetic thinking. A. Abdul-Rahman [1] compared the effectiveness of calculations in the time and frequency domains. Ch.H. Lin [7] proposed game-based methods built on the concept of the mental number line to improve children's fundamental mathematical skills.

A review of scientific literature reveals that, despite the abundance of experimental data, contradictions remain in the interpretation of cognitive mechanisms underlying mental arithmetic. For example, studies on neural activity identify different cortical areas responsible for arithmetic operations, but definitive conclusions regarding their interactions have not yet been reached. Additionally, the impact of external factors such as visual and auditory environments varies depending on research methodologies and individual differences among participants. The long-term effects of regular mental arithmetic training and its integration into educational programs also remain insufficiently explored.

The methodological framework of this study includes comparison, systematization, content analysis of scientific publications, synthesis, retrospective analysis, and generalization.

RESULTS AND DISCUSSIOn

Referring to the retrospective analysis (Fig. 1), it is appropriate to note that the origins of mental arithmetic trace back to methods used in ancient cultures to develop numerical perception. However, in modern science, this approach is examined through the lens of cognitive psychology and information theory.

Unlike traditional algorithmic learning schemes, the approach discussed in this article relies on a multi-component integration of visual, auditory, and motor processes, positioning it as a synthesis of intellectual training and neuroplasticity.

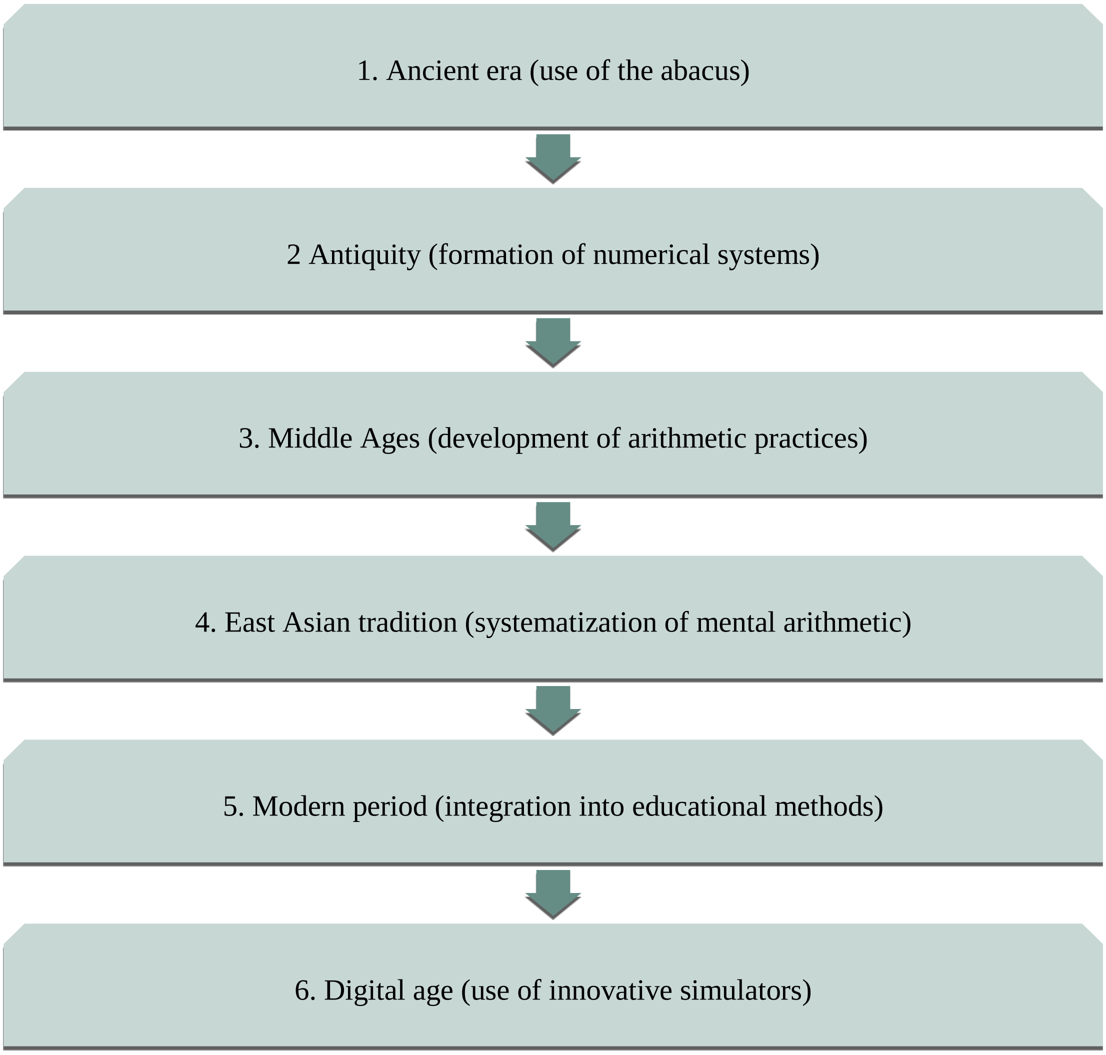

Fig. 1. A retrospective of the development of mental arithmetic (compiled by the author based on [2, 4, 10]

This approach represents the systematic execution of computational operations without the use of physical tools. It encompasses both basic arithmetic operations and more complex processes, including numerical sequence analysis and their transformation into abstract representations [1, 7].

Mathematical abilities in this framework are determined not only by the level of proficiency in computational algorithms but also by the degree of development in analytical thinking, the ability to abstract, and the capacity to switch quickly between different cognitive modes. Table 1 provides a description of key models.

Table 1 – Characteristics of cognitive information processing models in mental arithmetic (compiled by the author based on [2-6, 8, 10])

Model	**Description**
Information Theory and Working Memory Concepts	In theoretical studies, working memory, which has limited capacity and is critical for temporary information storage and processing, serves as a key element of analysis. The corresponding model, proposed by A. Baddeley, considers mental calculations as a dynamic process in which visual and verbal components integrate into a unified information system. During

Model	Description
	arithmetic operations, activation of the central executive component is observed, responsible for coordinating and controlling computational activities.
Neurocognitive Approach and Functional Distribution	Within neuropsychology, it has been demonstrated that mental arithmetic processes activate not only the prefrontal cortex, which is responsible for planning and control, but also temporal structures involved in processing numerical representations. This model highlights two primary pathways for information processing: one oriented towards numerical semantics and the other towards spatial-visual number perception. This dichotomy helps explain how regular mental arithmetic training contributes to the redistribution of neural resources and strengthens inter-cortical connections.
The "Mental Abacus" Concept	This approach suggests that the learner visualizes a traditional abacus and uses it as an internal model for performing calculations. This method optimizes numerical data processing and forms a stable cognitive strategy that enables manipulation of abstract representations without external aids. Theoretically, this mechanism can be viewed as a manifestation of neuroplasticity, where new informational schemes integrate into existing cognitive structures.

Next, it is necessary to describe the mechanism by which mental arithmetic influences mathematical thinking.

Unlike standard algorithmic memorization, this approach stimulates the development of flexible problem-solving strategies. Regular mental calculation practice enhances the ability to quickly recognize patterns and model alternative solutions. This process is characterized by a high degree of adaptability, allowing individuals to apply complex information-processing schemes when faced with non-standard situations.

One of the central mechanisms of mental arithmetic involves transforming abstract numerical concepts into concrete visual structures. During training, learners do not merely perform arithmetic operations but also visualize numerical relationships, which facilitates better memory retention and a deeper understanding of mathematical principles. This approach helps avoid the fragmentation of traditional methods and fosters a holistic perception of numerical relationships.

Neuroscientific research indicates the active involvement of various sensory systems in mental calculations. The combination of visual, auditory, and proprioceptive information enables multidimensional data encoding, which reduces the likelihood of errors and significantly accelerates decision-making. In

theoretical models, this phenomenon is described as a synergistic effect, where the integration of diverse signals leads to more stable and accurate computation performance [1, 6, 7].

Consider the following examples. If one needs to subtract 12 from 87, a common strategy is to break the smaller number into components—here, 12 consists of 10 and 2. Since subtracting 10 from any number is straightforward, one can first subtract 10 from 87, yielding 77. Then, subtracting 2 from 77 results in 75.

A mental addition method is commonly used when a number contains 8 or 9 in the units place. To add 9 to any number, one can first add 10 and then subtract 1.

As noted by W. Ross and colleagues, children under the age of 10 exhibit a greater reliance on counting and cognitive effort in processing numerical information compared to older children [11].

In a study involving 52 third-grade students, L. Dawei and colleagues used graphical educational aids based on mental arithmetic strategies and schema theory. After a 14-day training period, the experimental group demonstrated significant improvements in speed, accuracy, and consistency in mental addition and subtraction. Both addition and subtraction tests in the control and experimental groups showed outstanding effectiveness of schema-based training in terms of reaction time (RTM) and error rate (ER). Pre-test RTM scores were nearly identical between the control and experimental groups, but the reduction in post-test duration in the experimental group was 1.69 times greater for addition and 2.34 times greater for subtraction compared to the control group [12].

The author proposes a conceptual "framework" model illustrating the influence of mental arithmetic on the development of mathematical abilities. This model incorporates several interconnected components (Fig. 2).

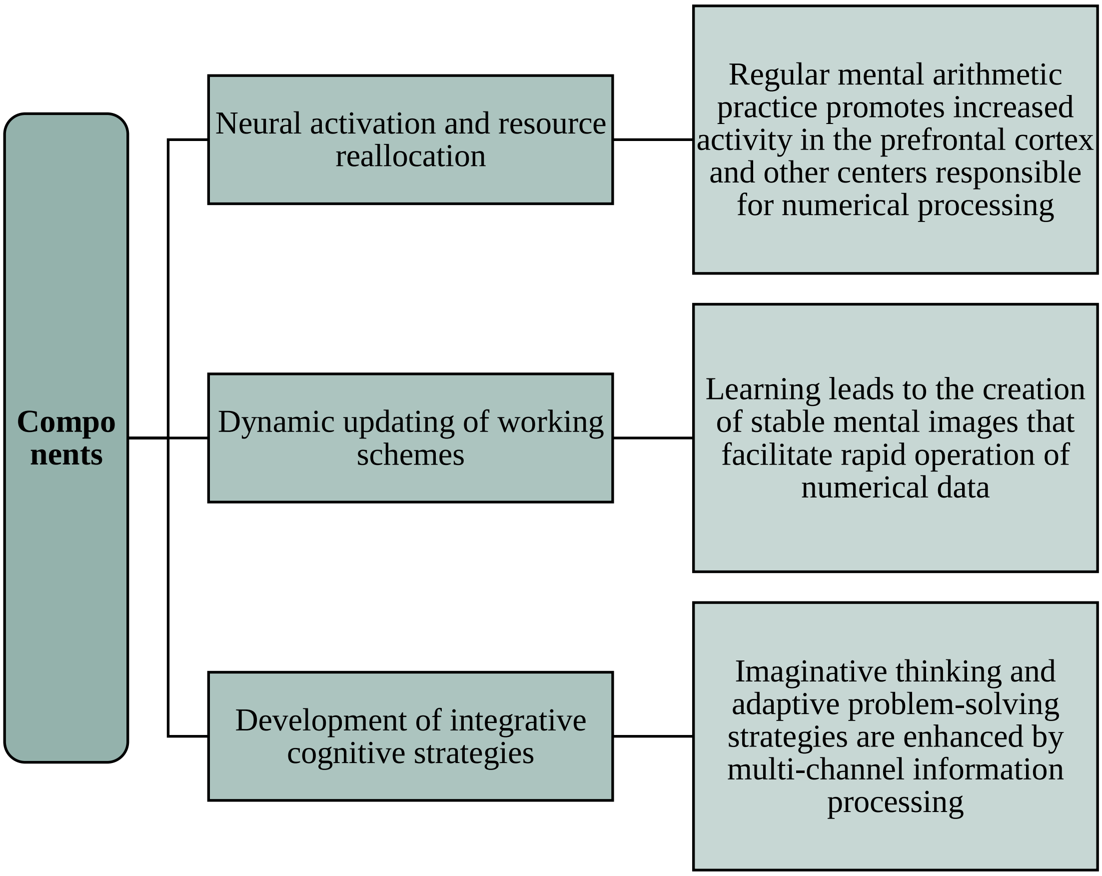

Fig. 2. The "framework" of the model of the influence of mental arithmetic on the development of mathematical abilities (compiled by the author)

The model substantiates the inclusion of mental arithmetic in educational programs based on a systematic approach to cognitive skill development. Methodologically, this implies a shift from mechanistic repetition of algorithms to the conscious formation of computational strategies, enabling students to develop a deeper understanding of mathematical principles and apply them in new contexts. Particular emphasis is placed on fostering independent problem analysis combined with the search for unconventional solutions.

To analyze the described influence, it is necessary to establish a set of criteria reflecting both quantitative and qualitative shifts in cognitive functioning. Among them, the following stand out:

- Information processing speed (changes in reaction time when performing arithmetic tasks serve as an indicator of cognitive improvement).
- Depth of visual representation (assessment of the ability to visualize numerical structures through specialized tests).
- Level of strategy adaptability (analysis of switching between different problem-solving methods and cognitive flexibility in non-standard situations).

Future research should be oriented toward interdisciplinary approaches that integrate neuroscience, cognitive psychology, and pedagogy. One promising objective is the development of models that account for individual variations in neural architecture, facilitating the adaptation of mental arithmetic methods to the specific cognitive profiles of learners.

In a theoretical context, the approach discussed in this article should be viewed as a means of forming adaptive frameworks capable of adjusting to changes in the educational environment. Investigating the dynamics of neural connections during regular mental computations will contribute to the creation of algorithms that optimize the learning process while considering individual cognitive characteristics.

Integrating data from neuroscience and pedagogy presents new opportunities for developing comprehensive educational programs where mental arithmetic serves as a central component. This approach not only enhances the effectiveness of mathematics education but also stimulates the development of related functions, including critical thinking and multitasking ability.

One challenge is the risk of a reductionist approach, where complex cognitive processes are reduced to purely neural models. Despite the high potential of neuroimaging, it is essential to recognize that computational abilities develop under the influence of cultural, pedagogical, and individual factors. Thus, a multi-level analysis is recommended, in which biological mechanisms are considered in conjunction with the social and psychological aspects of learning.

Another significant aspect is the development of metacognitive skills, which help students become aware of their own thought processes. Mental arithmetic, by requiring continuous monitoring of calculations, fosters self-regulation and self-control, which are crucial components of academic success. Theoretically, this phenomenon aligns with the concept of reflective thinking, where awareness of one's cognitive strategies enables individuals to adjust and optimize information processing.

A critical analysis of the proposed "framework" model reveals several limitations associated with the variability of individual cognitive resources. On the other hand, its potential lies in the ability to adapt mental arithmetic techniques to specific educational and psychological conditions. This opens up prospects for the development of personalized programs that emphasize adaptability rather than universal applicability, ensuring that instructional methods align with the unique characteristics of each learner.

CONCLUSIONS

This study attempted to analyze the impact of mental arithmetic on the development of mathematical abilities. Models of working memory, neurocognitive mechanisms, and sensory system integration demonstrate that regular training in mental calculations contributes to the formation of stable cognitive strategies and the development of visual thinking.

The development of a comprehensive theoretical foundation that considers both biological and cultural-pedagogical factors is a crucial step toward optimizing educational practices and designing adaptive learning programs.

The advancement of metacognitive skills, critical analysis of reductionist approaches, and interdisciplinary collaboration appear to be promising directions for future research.

Thus, mental arithmetic functions not only as a method for training computational skills but also as a comprehensive tool that fosters flexible, adaptive, and profound mathematical thinking.

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