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Integration of mental arithmetic into the STEM education system as a means of stimulating the analytical thinking of learners

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Abstract. The relevance *of the study is determined by the increasing role of analytical thinking in the contemporary educational environment and the growing need to implement innovative approaches to the development of learners' cognitive competencies within the expanding system of STEM education. Under conditions of digitalization and increasing complexity of interdisciplinary educational processes, particular importance is attached to identifying effective educational instruments capable of enhancing logical reasoning, concentration, cognitive flexibility, and rapid decision-making abilities. In this context, mental arithmetic is considered not only as a method of accelerated calculations, but also as a cognitive and pedagogical instrument for stimulating learners' analytical abilities.* ***The purpose*** *of the article is to determine the educational potential and substantiate the effectiveness of integrating mental arithmetic into the system of STEM education for stimulating the analytical thinking of learners.* ***The research methods*** *are based on theoretical generalization, analysis and synthesis of scientific sources, a logical-*

analytical approach, and the systematization of contemporary pedagogical and methodological approaches to integrating mental arithmetic into STEM-oriented learning. ***As a result*** *of the study, the pedagogical essence of mental arithmetic and its functional role in the development of analytical thinking, cognitive stability, and interdisciplinary competencies of learners have been clarified. The influence of mental arithmetic practices on the formation of logical reasoning, concentration, operational memory, and the ability to process information under dynamic educational conditions has been investigated. Methodological approaches to integrating mental arithmetic into STEM-oriented educational models, including project-oriented, adaptive, simulation-based, and collaborative learning, have been substantiated. Key scientific and practical problems associated with insufficient methodological standardization, risks of learning mechanization, cognitive overload, and unequal educational resource provision have been identified. It has been proven that the effectiveness of integrating mental arithmetic substantially increases when combined with interdisciplinary STEM practices, digital technologies, and adaptive educational models.* ***The conclusions*** *establish that mental arithmetic functions as an effective instrument for stimulating analytical thinking and developing learners' cognitive flexibility within the contemporary STEM environment. Prospects for further research are associated with the empirical verification of the long-term influence of mental arithmetic on the formation of analytical competencies, as well as with the development of standardized models for its integration into digital STEM-oriented educational systems.*

Keywords: *cognitive development, logical reasoning, interdisciplinary learning, educational technologies, cognitive flexibility, mathematical modeling, attention concentration, adaptive learning.*

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Інтеграція ментальної арифметики в систему STEM-освіти як засіб стимулювання аналітичного мислення здобувачів освіти

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Анотація. Актуальність дослідження *зумовлена зростанням ролі аналітичного мислення у сучасному освітньому середовищі та посиленням потреби у впровадженні інноваційних підходів до розвитку когнітивних компетентностей здобувачів освіти в умовах поширення STEM освіти. В умовах цифровізації та ускладнення міждисциплінарних освітніх процесів актуалізується необхідність пошуку ефективних інструментів, здатних забезпечити розвиток логічного мислення, концентрації уваги, когнітивної гнучкості та здатності до оперативного прийняття рішень. У зв'язку з цим ментальна арифметика розглядається не лише як методика швидких обчислень, а як когнітивний та педагогічний інструмент розвитку аналітичних здібностей здобувачів освіти.* ***Метою статті*** *є визначення освітнього потенціалу та обґрунтування ефективності інтеграції ментальної арифметики у систему STEM-освіти для стимулювання аналітичного мислення здобувачів освіти. Методи дослідження ґрунтуються на використанні теоретичного узагальнення, аналізу та синтезу наукових джерел, логіко-аналітичного підходу, а також систематизації сучасних педагогічних і методичних підходів до інтеграції ментальної арифметики в STEM-орієнтоване навчання.* ***У результаті*** *дослідження уточнено педагогічну сутність ментальної арифметики та визначено її функціональну*

роль у розвитку аналітичного мислення, когнітивної стійкості та міждисциплінарних компетентностей здобувачів освіти. Досліджено вплив практик ментальної арифметики на формування логічного мислення, концентрації уваги, оперативної пам'яті та здатності до обробки інформації в умовах динамічного освітнього середовища. Обґрунтовано методичні підходи до інтеграції ментальної арифметики у STEM-орієнтовані освітні моделі, зокрема проєктно-орієнтоване, адаптивне, симуляційне та колаборативне навчання. Виявлено ключові наукові та практичні проблеми, пов'язані з недостатньою методичною уніфікацією, ризиками механізації навчального процесу, когнітивним перевантаженням та нерівномірністю ресурсного забезпечення освітніх закладів. Доведено, що ефективність інтеграції ментальної арифметики суттєво зростає за умови її поєднання з міждисциплінарними STEM-практиками, цифровими технологіями та адаптивними освітніми моделями. ***У висновках*** *встановлено, що ментальна арифметика виступає ефективним інструментом стимулювання аналітичного мислення та розвитку когнітивної гнучкості здобувачів освіти в сучасному STEM-середовищі. Перспективи подальших досліджень пов'язані з емпіричною перевіркою довгострокового впливу ментальної арифметики на формування аналітичних компетентностей, а також із розробленням стандартизованих моделей її інтеграції у цифрові STEM-орієнтовані освітні системи.*

Ключові слова: *когнітивний розвиток, логічне мислення, міждисциплінарне навчання, освітні технології, когнітивна гнучкість, математичне моделювання, концентрація уваги, адаптивне навчання.*

Problem statement. The rapid transformation of contemporary education under the influence of digital technologies, interdisciplinary approaches, and competency-oriented learning has intensified the need to develop analytical thinking

as a fundamental cognitive component of learners' intellectual activity. Within the system of science, technology, engineering, and mathematics (STEM) education, particular significance is attached not only to mastering mathematical knowledge but also to forming the ability to process information logically, identify patterns, make reasoned decisions, and operate effectively in conditions requiring concentration and rapid cognitive adaptation. In this context, mental arithmetic is increasingly considered not merely as a technique for accelerated calculations, but as an educational instrument capable of activating cognitive processes associated with memory, attention, spatial imagination, and analytical reasoning.

At the same time, the practical integration of mental arithmetic into STEM-oriented educational environments remains fragmented and methodologically inconsistent. Existing educational approaches are predominantly focused on technical aspects of computational skills, whereas insufficient attention is devoted to substantiating the developmental potential of mental arithmetic in the formation of analytical thinking and interdisciplinary competencies. The lack of clearly structured pedagogical models for combining mental arithmetic with STEM methodologies limits the effectiveness of its implementation in modern educational practice. Under such conditions, the study of conceptual, methodological, and practical foundations of integrating mental arithmetic into the STEM education system acquires particular scientific and applied significance, since it is directly related to improving the quality of cognitive training and strengthening the intellectual adaptability of learners in the contemporary educational environment.

Analysis of recent research and publications. A review of contemporary research demonstrates the growing scientific interest in the integration of mental arithmetic, STEM approaches, and digital educational technologies in the context of developing learners' analytical thinking skills. K. Novik et al. substantiate the role of social media and online communities as tools for supporting collaborative learning and cognitive interaction under conditions of digital transformation in

education [1]. In subsequent studies, K. Novik analyzes the potential of artificial intelligence (AI) in creating adaptive learning environments for teacher education [2] and determines the influence of AI on the transformation of teaching methods and the effectiveness of online education [3]. H. M. Antonenko et al. investigate the role of distance technologies in ensuring the resilience of Ukrainian higher education, emphasizing the importance of digital competencies and flexible educational models [4]. L. Y. Petryshyn et al. examine the digital transformation of universities in the context of sustainable development and global knowledge competition, highlighting the significance of integrating innovative educational technologies [5]. V. Tytarenko and N. Nahorna substantiate the role of STEM technologies as instruments for the adaptive preparation of higher education students for the challenges of an innovative society, identifying interdisciplinarity and practical orientation as key factors in the development of analytical thinking [6].

At the same time, a separate line of research focuses on mathematical education and the development of learners' cognitive abilities. V. Borysenko analyzes approaches to the formation of mathematical competencies through the use of real-life examples, emphasizing the relationship between mathematical thinking and personality development [7]. R. Hidayat et al., in a systematic review, define analytical thinking as one of the core competencies of STEM education and demonstrate the effectiveness of integrated learning methods for its development [8]. P. Chowdhury investigates pedagogical approaches aimed at reducing math anxiety and strengthening STEM pathways, emphasizing the necessity of developing confidence in mathematical activity [9]. N. Phuseengoen and J. Singhchainara prove the effectiveness of STEM-integrated movement activities in developing students' analytical thinking skills [10]. M. Wang et al., in a systematic literature review on analytical thinking development in mathematics education, emphasize the importance of cognitively oriented methodologies and interdisciplinary integration [11].

Furthermore, a substantial body of research is devoted to the integration of computational thinking and innovative educational models into STEM environments. N. Nikmah and A. Suwito consider cognitive psychology as a foundation for integrating computational thinking into mathematics education, identifying logical knowledge structuring as an important factor in the development of analytical abilities [12]. B. Chen et al., in a meta-analysis of integrated STEM education, demonstrate the positive influence of STEM integration on students' academic achievements and cognitive competency development [13]. M. I. Simeon et al. investigate the effectiveness of the design thinking approach in STEM learning, emphasizing its significance for the development of problem-solving and analytical thinking skills [14]. H. Y. Lee et al. analyze the integration of computational thinking into scaffolding learning as an innovative approach to enhancing hands-on STEM learning effectiveness [15].

Therefore, contemporary studies confirm the significant potential of STEM-oriented, digital, and cognitively integrated educational approaches in developing learners' analytical thinking skills. At the same time, the issue of integrating mental arithmetic into the STEM education system as a comprehensive instrument for stimulating analytical thinking remains insufficiently explored, particularly regarding methodological support, interdisciplinary integration, and practical adaptation to the contemporary digital educational environment.

Identification of previously unresolved parts of the general problem. Despite the growing interest in the use of mental arithmetic within STEM education, its developmental potential in stimulating analytical thinking remains insufficiently substantiated. Existing research is primarily concentrated on computational skills and cognitive activation, whereas the interdisciplinary and methodological dimensions of integrating mental arithmetic into STEM-oriented learning environments have received limited scientific attention.

The relevance of these unresolved aspects is determined by the increasing demand for educational approaches capable of developing cognitive flexibility, logical reasoning, and adaptive analytical competencies in contemporary learners. Addressing these issues is essential for improving the methodological coherence and practical effectiveness of STEM-oriented educational models based on interdisciplinary cognitive interaction.

Formulation of the objectives of the article (task setting). The purpose of the article is to determine the educational potential and substantiate the effectiveness of integrating mental arithmetic into the system of STEM education for stimulating the analytical thinking of learners.

Objectives of the article:

1. To determine the pedagogical role of mental arithmetic in the development of analytical competencies within STEM education.

2. To substantiate approaches to integrating mental arithmetic into STEM-oriented learning processes.

3. To identify implementation problems and develop recommendations for improving the effectiveness of mental arithmetic in stimulating analytical thinking.

Main findings. Mental arithmetic in the contemporary educational environment is increasingly regarded as a pedagogical instrument that extends beyond the formation of computational skills and contributes to the activation of cognitive processes related to concentration, logical reasoning, memory, and analytical information processing. Within the system STEM education, its educational value is associated with the development of flexible thinking, rapid decision-making, and the ability to identify structural relationships in complex tasks. The pedagogical essence of mental arithmetic is therefore manifested through its capacity to combine numerical activity with the development of analytical and interdisciplinary cognitive competencies (table 1).

Table 1

Pedagogical characteristics of mental arithmetic and its functional role in the development of analytical thinking within STEM education

Component	Substantive characteristic	Manifestation in the educational process	Functional significance for analytical thinking
Cognitive	Activation of mental processes associated with calculations and information processing	Rapid numerical operations, memorization of combinations, concentration exercises	Enhances logical reasoning and information structuring
Analytical	Formation of the ability to identify patterns and relationships	Solving non-standard mathematical tasks, sequence analysis	Develops analytical and problem-solving skills
Adaptive	Development of intellectual flexibility under changing learning conditions	Switching between tasks, rapid correction of mistakes	Strengthens cognitive adaptability and decision-making speed
Interdisciplinary	Integration of mathematical thinking with technological and engineering tasks	Application of calculations in STEM-oriented projects and simulations	Supports interdisciplinary analytical interaction
Motivational	Stimulation of sustained engagement in cognitive activity	Interactive exercises, competitive educational methods	Increases involvement and continuity of intellectual activity

Source: developed by the author based on [2, p. 190; 6; 8, p. 572; 10, p. 514; 11; 12, p. 283; 13, p. 641].

The practical significance of the presented characteristics becomes particularly evident in contemporary STEM-oriented educational models, where learners are expected not only to reproduce knowledge but also to operate effectively in situations requiring analytical interpretation and rapid cognitive response. Mental arithmetic exercises are actively integrated into project-based learning, robotics classes, engineering simulations, and mathematical modeling tasks, where students must process numerical information under time constraints and simultaneously maintain logical consistency in decision-making. For example, during robotics programming activities, learners applying mental calculation techniques demonstrate faster identification of algorithmic errors and more stable attention

during sequential operations [2, p. 190]. In engineering-oriented classroom tasks, rapid numerical analysis supports more effective interpretation of measurement data and improves the ability to recognize quantitative relationships between variables.

An equally important practical effect is observed in the development of cognitive endurance and intellectual adaptability. In modern educational environments characterized by high informational intensity, learners frequently encounter fragmented attention and difficulties in maintaining analytical concentration. Systematic integration of mental arithmetic into STEM learning activities contributes to strengthening operational memory and increasing resistance to cognitive overload, particularly during complex interdisciplinary assignments combining mathematical, technological, and logical components [12, p. 283]. This creates conditions in which analytical thinking develops not as an isolated mathematical skill, but as an integrated cognitive mechanism directly connected with problem-solving efficiency, structured reasoning, and intellectual flexibility in real educational practice.

Mental arithmetic practices within the system of STEM education contribute not only to the improvement of numerical performance, but also to the formation of cognitive mechanisms associated with logical reasoning, concentration stability, and interdisciplinary problem-solving. Their educational influence is manifested through the activation of analytical operations that require learners to coordinate memory, attention, visualization, and rapid information processing within dynamic learning conditions (table 2).

Table 2

Influence of mental arithmetic practices on the formation of learners' cognitive, logical, and interdisciplinary competencies

Competency direction	Educational manifestation	Mechanisms of influence through mental arithmetic	Resulting educational effect

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Cognitive stability	Sustained concentration during intellectually intensive tasks	Simultaneous activation of memory, attention, and visualization processes	Improvement of information retention and mental endurance
Logical reasoning	Ability to construct consistent analytical sequences	Rapid identification of numerical and structural relationships	Strengthening of deductive and analytical thinking
Interdisciplinary integration	Transfer of mathematical logic into other educational domains	Application of calculation strategies in technological and engineering tasks	Development of integrated problem-solving skills
Decision-making flexibility	Adaptation to variable educational conditions and task complexity	Instant correction of calculation strategies and cognitive responses	Increase in intellectual adaptability
Information coordination	Simultaneous processing of multiple informational elements	Combination of visual, numerical, and analytical operations	Enhancement of multidimensional cognitive processing

Source: developed by the author based on [6; 7, c. 371; 8, p. 575; 9, p. 148; 10, p. 515; 11; 12, p. 284; 13, p. 648].

The influence of mental arithmetic practices on competency formation becomes particularly evident in contemporary STEM-oriented educational environments, where learners are required to combine analytical reasoning, rapid information processing, and interdisciplinary interaction within a unified cognitive activity. Unlike traditional forms of mathematical training focused mainly on computational accuracy, mental arithmetic practices create conditions for the simultaneous activation of several intellectual mechanisms associated with concentration control, logical sequencing, adaptive thinking, and operational decision-making [6]. This substantially expands their pedagogical value in the context of competency-based education.

In practical educational settings, such influence is observed during tasks that require learners to process quantitative information under dynamically changing conditions. For instance, within coding and algorithmic exercises, students applying mental arithmetic strategies more effectively identify inconsistencies in logical sequences and maintain procedural coherence while modifying computational

parameters. During interdisciplinary STEM projects involving robotics, digital modeling, or experimental analysis, rapid mental calculations support faster interpretation of numerical relationships and improve the ability to correlate mathematical data with technological outcomes [8, p. 575]. This contributes to the formation of analytical stability rather than isolated numerical proficiency.

A significant practical effect also concerns the development of intellectual flexibility under conditions of informational overload characteristic of modern digital education. Learners systematically engaged in mental arithmetic activities demonstrate greater resistance to attentional fragmentation during multitask educational processes, particularly when several analytical operations must be coordinated simultaneously. In project-based learning, this is reflected in improved capacity to compare variables, predict possible outcomes, and adapt reasoning strategies when initial assumptions change. Such competencies are critically important in contemporary STEM education, where effective learning increasingly depends on the ability to integrate logical analysis, cognitive endurance, and interdisciplinary interpretation within real-time problem-solving situations.

The integration of mental arithmetic into STEM-oriented educational models requires the development of methodological approaches capable of ensuring not only the acquisition of computational skills, but also the formation of sustainable analytical, technological, and problem-oriented competencies. In contemporary educational practice, the effectiveness of such integration depends on the coordination between cognitive training methods, interdisciplinary educational content, and adaptive instructional technologies. Mental arithmetic in this context should be considered as a structural element of the educational process that supports analytical interaction between mathematical reasoning, technological application, and practical problem-solving within competency-based learning environments (table 3).

Table 3

Methodological approaches to integrating mental arithmetic into STEM-oriented educational models and learning processes

Methodological approach	Educational implementation format	Pedagogical integration mechanism	Expected developmental outcome
Project-oriented	Inclusion of mental calculations in interdisciplinary STEM projects	Application of rapid numerical analysis during problem-solving activities	Strengthening of analytical and applied thinking
Simulation-based	Use of virtual and technological learning environments	Integration of calculation tasks into digital simulations and modeling	Improvement of operational decision-making skills
Adaptive learning	Personalization of cognitive workload and task complexity	Adjustment of exercises according to learners' analytical performance	Enhancement of individual cognitive development
Problem-centered	Combination of mental arithmetic with real-world analytical tasks	Use of non-standard quantitative scenarios requiring logical interpretation	Development of strategic reasoning abilities
Collaborative-interactive	Organization of group analytical activities	Joint execution of interdisciplinary tasks involving numerical coordination	Formation of communicative and interdisciplinary competencies

Source: developed by the author based on [2, p. 191; 5; 6; 8, p. 579; 13, p. 653; 14, p. 193; 15, p. 224].

Applicability of these methodological approaches becomes especially significant in educational environments where analytical activity is closely connected with technological interaction and interdisciplinary task execution. In modern STEM education, mental arithmetic demonstrates the highest effectiveness when integrated into educational situations requiring rapid quantitative interpretation, logical adaptation, and continuous cognitive coordination rather than isolated repetitive calculations [15, p. 224]. This shifts its pedagogical role from computational training toward the development of operational analytical behavior applicable across different educational contexts. For instance, within project-

oriented STEM learning, mental arithmetic is effectively embedded into engineering and design assignments where learners must estimate dimensions, compare technical parameters, or evaluate proportional relationships during the construction of prototypes and digital models. In robotics education, rapid mental calculations support faster calibration of movement algorithms, sensor synchronization, and evaluation of trajectory changes without interrupting the practical workflow. Such integration substantially increases learners' ability to combine mathematical reasoning with technological interpretation in real time [6]. Simulation-based approaches also reveal considerable practical potential. During interaction with virtual laboratories or digital STEM simulators, learners frequently operate in conditions requiring immediate numerical interpretation of changing variables. Mental arithmetic techniques reduce dependency on external computational tools in elementary analytical stages, allowing students to focus more effectively on interpreting experimental outcomes and identifying logical inconsistencies within models. This is particularly relevant in educational environments emphasizing engineering experimentation, data analysis, and predictive reasoning. Equally important is the role of adaptive and collaborative methodological models. In adaptive digital learning systems, mental arithmetic tasks can be differentiated according to learners' cognitive responsiveness and analytical stability, which supports individualized intellectual development without weakening interdisciplinary integration [14, p. 193]. Collaborative-interactive approaches, in turn, create conditions where numerical reasoning becomes part of collective analytical communication. During group STEM projects, learners jointly interpret quantitative indicators, distribute analytical functions, and coordinate logical decisions while solving complex practical tasks. Under such conditions, mental arithmetic evolves into a methodological mechanism that supports analytical flexibility, interdisciplinary coordination, and sustainable cognitive engagement within contemporary educational practice.

Despite the growing integration of mental arithmetic into the system of STEM education, its implementation remains associated with several scientific and practical problems that limit the effectiveness and sustainability of educational outcomes. One of the key challenges is the absence of unified methodological approaches to incorporating mental arithmetic into interdisciplinary educational models. In many cases, it is still taught as an isolated computational practice rather than as a cognitive instrument connected with analytical reasoning, technological interpretation, and problem-oriented learning [9, p. 148]. This significantly narrows its developmental potential within contemporary STEM education. An important scientific problem concerns the insufficient empirical substantiation of the long-term educational effects of mental arithmetic. Existing studies are predominantly focused on short-term improvements in concentration, memory, or calculation speed, whereas considerably less attention is devoted to evaluating the stability of analytical thinking, interdisciplinary transferability of competencies, and adaptability of learners in dynamic educational environments. This complicates the formation of evidence-based pedagogical models and objective criteria for assessing educational effectiveness. Practical implementation is further complicated by the uneven methodological preparedness of teachers. Effective integration of mental arithmetic into STEM-oriented learning requires the ability to combine cognitive, mathematical, technological, and project-based instructional approaches [6]. However, many educational practices remain limited to repetitive calculation exercises without meaningful analytical or interdisciplinary integration. As a result, learners may develop operational computational skills while demonstrating insufficient ability to apply them in complex educational situations.

Another significant issue is the risk of excessive mechanization of learning. Under conditions where speed and numerical accuracy become dominant educational priorities, mental arithmetic may gradually lose its analytical and developmental orientation. In such cases, learning processes become overly

algorithmized, reducing opportunities for reflective reasoning, conceptual understanding, and creative problem-solving. This is particularly problematic within STEM education, where analytical flexibility and interdisciplinary interpretation are more important than isolated computational performance. Contemporary digital educational environments also create additional difficulties associated with attentional fragmentation and cognitive overload. Learners frequently operate under conditions of constant informational stimulation, which complicates the maintenance of concentration required for systematic mental arithmetic practice. In some situations, intensive cognitive demands may contribute to mental fatigue, decreased motivation, or increased anxiety among learners with different levels of cognitive preparedness. Practical limitations are also linked to disparities in educational infrastructure and access to specialized instructional resources. The successful integration of mental arithmetic into STEM education often depends on adaptive digital tools, qualified instructors, and interdisciplinary teaching materials that are not equally available across educational institutions. Consequently, the implementation quality of such educational models remains uneven and methodologically inconsistent.

The improvement of the effectiveness of integrating mental arithmetic into the system of STEM education requires the implementation of coordinated pedagogical, methodological, and organizational measures aimed at strengthening its analytical and interdisciplinary educational potential. One of the priority directions involves shifting mental arithmetic from the status of an isolated computational discipline toward its integration into problem-oriented and project-based educational activities. The inclusion of rapid numerical analysis within engineering tasks, mathematical modeling, robotics, and digital simulations allows learners to perceive mental arithmetic not as repetitive calculation training, but as a practical cognitive instrument for analytical reasoning and operational decision-making.

An important recommendation concerns the development of adaptive methodological models that account for differences in learners' cognitive responsiveness, concentration stability, and analytical preparedness. The differentiation of task complexity, learning tempo, and forms of numerical interaction contributes to reducing cognitive overload and increases the sustainability of intellectual engagement during STEM-oriented activities. Under contemporary educational conditions, such adaptation can be effectively supported through digital educational platforms capable of dynamically adjusting analytical tasks according to learners' performance indicators.

Considerable attention should also be devoted to strengthening the interdisciplinary integration of mental arithmetic with technological and engineering educational components. The effectiveness of analytical thinking development substantially increases when mental calculation practices are combined with coding activities, experimental data interpretation, algorithmic analysis, and applied engineering tasks. This approach supports the transfer of mathematical reasoning into broader educational contexts and strengthens learners' ability to apply analytical logic in practical problem-solving situations.

Another important direction involves improving teachers' methodological preparedness for interdisciplinary STEM instruction. Educational effectiveness largely depends on educators' ability to integrate cognitive activation techniques, analytical exercises, and technological learning tools within a unified instructional environment. For this reason, professional development programs should include specialized training focused on adaptive STEM methodologies, interdisciplinary project coordination, and the pedagogical use of mental arithmetic within digitally oriented educational systems.

It is also advisable to avoid excessive concentration on computational speed as the dominant indicator of educational success. Assessment approaches should emphasize the quality of analytical reasoning, logical consistency, adaptability of

decision-making, and the ability to interpret quantitative relationships within interdisciplinary tasks. Such a shift allows mental arithmetic to function as a mechanism for developing sustainable analytical thinking rather than merely accelerating numerical operations.

The practical effectiveness of integration can be additionally strengthened through collaborative and research-oriented learning formats. Group analytical projects, technological case studies, and interdisciplinary STEM laboratories create conditions in which learners apply mental arithmetic within real educational interactions requiring coordination of quantitative analysis, logical interpretation, and collective problem-solving. Under such conditions, mental arithmetic becomes integrated into the broader structure of cognitive and interdisciplinary competency development characteristic of contemporary education.

Conclusions. Conclusions. The study substantiates that the integration of mental arithmetic into the system of STEM education possesses significant pedagogical potential for stimulating the analytical thinking of learners. It has been established that mental arithmetic should be considered not only as a computational technique, but also as a cognitive instrument that contributes to the development of concentration, logical reasoning, operational memory, analytical flexibility, and interdisciplinary problem-solving. The research demonstrates that the effectiveness of mental arithmetic substantially increases under conditions of its integration into project-oriented, adaptive, simulation-based, and collaborative STEM learning models. It has been determined that systematic mental arithmetic practices positively influence cognitive stability, analytical responsiveness, and the ability to process quantitative information within dynamic educational environments. At the same time, the study identifies several key scientific and practical problems, including the lack of unified methodological approaches, insufficient empirical verification of long-term educational effects, uneven methodological preparedness of teachers, risks of excessive mechanization of learning, and cognitive overload in digitally

saturated educational systems. Additional limitations are associated with disparities in access to adaptive technologies and interdisciplinary instructional resources. The proposed recommendations are focused on strengthening the analytical and interdisciplinary orientation of mental arithmetic through its integration into engineering tasks, robotics, mathematical modeling, coding activities, and digital simulations. Considerable importance is attached to adaptive learning models, differentiation of cognitive workload, collaborative analytical activities, and improvement of teachers' methodological competencies in STEM-oriented instruction. It is substantiated that educational assessment should emphasize analytical reasoning, logical consistency, and adaptability of decision-making rather than isolated calculation speed.

Prospects for further research are associated with the empirical evaluation of the long-term influence of mental arithmetic on analytical thinking development, the creation of standardized methodological frameworks for STEM integration, and the development of adaptive digital educational technologies for personalized cognitive training.

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