Vol. 24 (2026): Proceedings of the 2nd International Conference on Linguistics, Psychology and Creative Education (ICLPCE 2026)
E-ISSN: 3105-0522 P-ISSN：3105-0514
DOI: https://doi.org/10.70267/iclpce.2026297303

A Review of Methods for Generating AI to Drive Cognitive Development in Junior High School Mathematics Education

Keyi Shen*

Taizhou University, Zhejiang, China

**Corresponding author: Keyi Shen.*

Abstract

The learning of junior high school mathematics often becomes a bottleneck in students' cognitive development due to its high abstraction and strong logic. Traditional classroom teaching is unable to take into account individual differences. The deep integration of artificial intelligence and mathematics education provides a new possibility for this. It adopts the literature review method to systematically explore the cognitive development support models of generative AI in junior high school mathematics teaching, including visual design, intelligent diagnosis, hierarchical push, and real-time interaction. It also focuses on analyzing the positive effects of generative AI in enabling personalized teaching on the cultivation of mathematical thinking, while also revealing the mechanism shortcomings and the problems such as cognitive inertia and weakened independent thinking that may arise from its excessive use. Studies have shown that generative AI can significantly enhance conceptual understanding and logical reasoning abilities, but it also has limitations such as insufficient non-logical cognitive processing and insufficient space for resolving cognitive conflicts. Excessive reliance on it may hinder the natural transformation of thinking. This review aims to provide theoretical references for the boundaries of using generative AI in mathematics teaching, while summarizing the existing controversies and shortcomings in current research, and offering systematic practical insights for future human-machine collaborative cognitive development.

Keywords

generative AI, mathematics education, cognitive development, personalized teaching, mathematical thinking

1. Introduction

Mathematical thinking is an important part of basic education. However, in the junior high school stage, mathematics gradually transforms from simple and intuitive calculations to abstract logical problems. Due to the comprehensive cognitive demands of language comprehension and mathematical reasoning, many students encounter persistent difficulties in this area. At the same time, the class teaching system struggles to identify each student's weak points [1]. In this case, generative AI can promptly interact and provide feedback on each child's questions, and during their interaction with generative AI, their interest, perceived value, and motivation increase. Generative AI can enhance students' mathematical thinking and problem-solving tasks by cultivating problem-solving abilities and achieving personalized guidance [2]. Currently, the academic community at home and abroad has conducted a large number of practices and studies on generative AI + junior high school mathematics education, but there is still a need for further improvement in the systematic review of the cognitive development dimensions. Cognitive development refers to the dynamic evolution of students' learning process in mathematics, where they progress from surface-level calculations to deeper understanding, logical reasoning, and flexible application. This is manifested specifically in the structuring of knowledge, the refinement of thinking, the flexibility of strategies, and the enhancement of reflective ability. It is the core indicator that shifts from simple calculation to rational thinking. Mathematical cognition is the essential foundation of mathematical thinking: Without a basic understanding of mathematical concepts, formulas, and rules, mathematical thinking would be like cooking without rice. And mathematical thinking is the core driving force for the deepening of mathematical cognition: Simple mechanical memorization can only form shallow cognition; only through thinking processing can scattered knowledge be integrated into a structured cognitive system, achieving a profound understanding of the essence of mathematics. Generative AI teaching can break down complex mathematical knowledge into an animated format, creating a more intuitive teaching model. This helps students understand mathematical logic, cultivate their mathematical thinking, develop the habit of breaking down problems and conducting logical reasoning, and truly enhance their problem-solving abilities, enabling students to progress from being able to calculate to being able to think [3]. Generative AI can also use data collection and analysis to organize students’ mathematical learning situations, and in combination with their current learning status, provide targeted learning solutions for students. At the same time, through human-computer interaction, we aim to solve students' learning problems and provide a more effective way for the cultivation of students' core competencies. Through a comprehensive review of AI, we can achieve large-scale personalized education.

2. AI-Enabled Personalized Mathematics Learning

2.1 Visual and Contextualized Instructional Design

Abstraction is the main cognitive obstacle in mathematics learning. Artificial intelligence, through visualization and contextual design, transforms symbolic knowledge into intuitive and interactive learning objects. Tools such as dynamic geometry, function animations, and 3D modeling can visually present graphic transformations, formula derivations, and variable relationships, helping students establish the connection between imagery and symbols; contextual modules embed mathematical problems in real-life scenarios, engineering cases, or interesting tasks, enhancing the perception of meaning and learning engagement. Furthermore, generative AI can provide personalized feedback and guidance to students in the field of mathematics education. It can automatically adapt to the interaction rhythm and context type of students, slowing down the steps for those with weaker abilities and strengthening the step-by-step decomposition; providing expansionary exploration tasks for those with stronger abilities. As students progress, the personalized strategies are constantly adjusted. After achieving certain accomplishments, they are objectively evaluated [4]. The visualization strategies and the complexity of the context are dynamically adjusted to achieve a closed-loop guidance of adaptation-assessment-optimization of students' autonomous construction level of mathematical thinking. This model converts abstract symbols into operational representations, lowering the cognitive threshold and promoting the thinking of number and shape combination. This is one of the most mature directions for the application of generative AI in mathematics teaching at present, promoting students' development of spatial imagination, function thinking and geometric intuition in mathematical cognition.

2.2 Intelligent Learning Diagnosis and Adaptive Recommendations

The intelligent learning situation diagnosis is based on multi-source data, comprehensively capturing information such as classroom responses, homework completion, problem-solving paths, error types, and time distribution. It constructs a knowledge and cognitive map of students' individual understanding of mathematical abstract concepts. Through cluster analysis, association rule mining and prediction, generative AI automatically identifies knowledge gaps, error patterns and thinking bottlenecks, collects students' learning data, and uses artificial intelligence for in-depth analysis and evaluation, achieving an upgrade from vague judgment to precise positioning [5]. Gradually, it enhances students' logical reasoning, concept discrimination and mathematical thinking abilities. The scientificity and accuracy of the learning situation diagnosis determine the rationality of the stratified push and the effectiveness of the subsequent teaching intervention. Generative artificial intelligence precisely identifies students' knowledge blind spots and provides personalized suggestions for students at different levels [6]: for students with weak foundations, emphasis is placed on concept consolidation, step guidance, and error correction training; for average students, methods are strengthened, variations are practiced, and transfer applications are enhanced; for outstanding students, open-ended questions, exploration tasks, and cross-module comprehensive questions are provided. Stratification is not a static label but is continuously updated in real time to ensure that the training intensity and cognitive load are within the reasonable range that students' cognitive abilities can reach, maximizing the assistance in students' strategic transfer, metacognitive regulation, and development of mathematical thinking and cognitive abilities, forming a closed loop of mathematical thinking analysis-precise defect diagnosis-stratified push-dynamic evaluation.

2.3 Real-Time Interactive Learning Support

In addition to the post-class diagnosis and recommendations, the real-time interaction within the classroom by generative AI is also worthy of attention. Traditional classroom interactions usually exhibit a fragmented nature. When the teacher advances the teaching progress, it is difficult to provide detailed responses to the interaction feedback of each student, which can lead to students' questions arising during the learning process not being promptly resolved [7]. Gradually, cognitive gaps accumulate and eventually affect the construction of the overall knowledge system. The artificial intelligence-assisted learning system can intervene immediately and interact in real time [8], and guide students to find their own solutions through questions, prompts, and analogies. It helps students gradually establish the habit of self-correction and reflection. Meanwhile, real-time interaction also retains the flexibility of human conversation: students can ask questions at any time, and the system will adjust its response strategy based on the context. For example, students often do not understand what a determines the opening direction and size means. The teacher can draw several diagrams to explain, but the AI can do it more deeply: when a student mistakenly believes that the conclusion that the function always has a minimum value when $a > 0$ is always true (in fact, the domain also needs to be considered), AI will generate an interactive slider in real time, allowing the student to drag the value of a while showing the vertex coordinates and the corresponding function values at the boundaries of the domain. The AI will also proactively present a hypothetical situation: If the domain is restricted to [1,3] and the x-coordinate of the vertex is 0.5, would the minimum value still definitely be the vertex? Try dragging it from 0.5 to 2 and observe the changes in the function values at the interval endpoints. This model, to some extent, realizes the one-on-one tutoring experience and compensates for the lack of depth of interaction in classroom teaching. The improvement of students' interaction ability with AI enables them to freely ask questions. The AI then breaks down difficult points in simple language and provides analogical explanations, adapting to different levels of expression and comprehension rhythms. This favorable interaction environment increases students' initiative [9]. Through continuous dialogue, they improve their thinking chains and gradually develop their mathematical cognitive abilities of autonomous exploration and metacognitive monitoring.

3. The Dual Effects of Generative Al on Mathematical Thinking

3.1 Positive Effects: Facilitating Logical Thinking Development

Mathematical thinking mainly consists of components such as logical reasoning, abstract generalization, modeling construction, and spatial imagination. Among them, logical reasoning is the main axis that runs through the entire process. Firstly, it can precisely diagnose and provide personalized paths: The advancement of logical thinking follows a certain development sequence, and each student's starting point and pace vary greatly. Generative AI combines the cognitive laws of junior high school mathematical logical reasoning and the characteristics of error data [10] to generate corresponding mathematical cognitive portraits. Through repeated construction, reflection, and internalization, students gradually acquire stable mathematical rational thinking. The generative AI teaching uses a series of mechanisms such as diagnosis, visualization, dialogue, exploration, and metacognitive support to present the implicit thinking process in a clear manner, laying out a personalized logical thinking growth path for each student. Secondly, learning analysis and metacognitive scaffolding: One of the signs that logical thinking is maturing is that individuals can step outside their own thought process and conduct self-examination and adjustment. Generative AI tracks students' planning, monitoring, reflection and other behaviors throughout the process and provides them with a thinking habit report.

3.2 Current Limitations of Generative AI Mechanisms

Although artificial intelligence has demonstrated significant advantages in the personalized design, visual teaching, and real-time interaction of junior high school mathematics education, its teaching mechanism itself still has inherent limitations [11], which restrict its comprehensive promotion effect on cognitive development. These limitations do not stem from the immature technical implementation, but are rooted in the design logic and operation mechanism of the current generative AI teaching systems. The strategies adopted by AI systems in real-time interaction, such as questioning, prompting, and analogy, can enhance students' participation. However, there is a risk that the teaching objectives may gradually become blurred or deviate. Research shows that generative AI, when having open-ended conversations with students, is prone to being pulled away from the preset mathematical cognitive path by students' interests, incorrect assumptions, or ambiguous expressions [12]. The cognitive development theory indicates that moderate confusion periods and cognitive conflicts are crucial conditions for concept reorganization and the leap in logical ability. However, generative AI, in pursuit of interaction fluency and user satisfaction, tends to provide timely and accurate feedback and prompts. This objectively narrows the time window for students to engage in independent thinking, repeated deliberation, and self-correction. Students are guided to the correct path before they have fully experienced cognitive struggles, which easily leads to a reliance on the feedback from generative AI and weakens its inherent metacognitive monitoring and error-correction capabilities. In other words, the high efficiency of generative AI may actually deprive students of the opportunity for slow thinking. The current generation of AI-based learning situation diagnosis mainly relies on observable behavioral data (such as answering time, path, error types), but lacks the direct modeling ability for implicit cognitive processes (such as attention allocation, strategy hesitation, confidence judgment, knowledge transfer intention). It is difficult to accurately infer from students' simple inputs whether they think this way, whether they realize they are wrong, or whether they are trying different strategies. This modeling limitation leads to the generation AI's judgment of depth of understanding always remaining at the level of indirect speculation, and it is difficult to truly achieve a precise diagnosis of the cognitive structure.

4. Cognitive Risks of Excessive Generative AI Use

The generative AI teaching system, while enhancing learning efficiency and reducing cognitive load, may have profound negative effects on the mathematical cognitive development of junior high school students if it is frequently used or overly relied upon. These effects do not manifest immediately but gradually erode students' habits and abilities of independent thinking as the frequency and depth of human-machine interaction increase. The following analysis is conducted from three dimensions: cognitive inertia, weakening of independent thinking, and obstruction of thinking transformation.

4.1 Cognitive Inertia and Reduced Independent Thinking

Cognitive-offloading refers to the phenomenon where individuals, when faced with cognitive tasks, tend to transfer their thinking process to external tools, thereby reducing their own mental effort. In the context of generative AI teaching, this tendency is significantly amplified: when students encounter difficult problems, they no longer attempt to repeatedly deliberate, draw diagrams, make conjectures, or consult references; instead, they directly seek hints, steps, or answers from AI. The immediacy and high accuracy of generative AI make asking AI a more effortless and quicker option compared to thinking on their own. Studies have shown that cognitive inertia leads to a decline in metacognitive monitoring abilities: students gradually lose the ability to be aware of, evaluate, and regulate their own thinking processes [13]. In the process of solving mathematical problems, metacognitive monitoring manifests as internal dialogues such as Am I thinking this way correctly? Are there other methods? Where am I stuck? When generative AI frequently replaces these internal dialogues, students find it difficult to form a stable self-correction mechanism. Once they are out of the AI environment, such as during exams, students often exhibit significant thinking stagnation and anxiety. Furthermore, the weakening of independent thinking is also reflected in the simplification of problem-solving paths. Generative AI, in pursuit of teaching efficiency, often tends to guide students towards the standard optimal path rather than encouraging them to explore alternative, circuitous, trial-and-error, or unconventional thinking methods. Over time, students tend to rely on the only correct approach, lacking the habit of exploring multiple solutions, questioning the rationality of answers, and posing unconventional questions. This is a typical manifestation of strong algorithmic thinking and weak innovative thinking in mathematics education.

4.2 Disruption of Cognitive Development and Thinking Transformation

The junior high school stage is a crucial period for the transformation of mathematical thinking from concrete operations to formal operations, and from intuitive perception to logical reasoning. This transformation requires students to gradually construct an abstract conceptual system through appropriate cognitive conflicts and confusion. Excessive use of AI may hinder this natural process in the following two aspects. Firstly, the formation of mathematical thinking is not a smooth and gradual process; rather, it is accompanied by cognitive conflicts and reconstructions. For instance, when transitioning from arithmetic thinking to algebraic thinking, students must undergo multiple conceptual adjustments such as letters represent unknowns, letters represent variables, and letters can participate in operations. These adjustments usually require students to repeatedly explore mistakes. However, generative AI often tends to provide hints or simplified explanations immediately when it detects students' confusion, thus closing the critical window of cognitive conflicts. Although students can complete the tasks quickly, they fail to achieve the natural transformation of mathematical thinking. Secondly, the advanced form of mathematical ability is not merely the ability to solve certain types of problems, but the ability to actively extract, modify and combine existing strategies in new situations [14]. The cultivation of this ability to transfer strategies relies on students' adventurous attempts without the trial-failure-reflection-adjustment cycle. Because generative AI intervenes early and shortens or skips the failure stage, when students need to independently face unfamiliar problems, they lack the initiative for thinking and the resilience to resist setbacks, thus making it difficult for students' abilities to improve.

5. Current Challenges in Generative AI Implementation

At the school and system levels, there is a mismatch between infrastructure and evaluation systems. The effective implementation of generative AI-based mathematics teaching requires a stable network environment, sufficient terminal devices, and continuous technical maintenance. However, the digital divide between urban and rural areas, as well as among schools, remains significant, and some schools even fail to meet the basic conditions. The more fundamental problem lies in the conflict between the existing academic evaluation system and the concept of generative AI teaching: generative AI emphasizes process-based diagnosis, personalized growth, and thinking development, while final evaluations such as the mid-term and final exams still focus on standardized answers and score rankings. This evaluation mismatch makes it difficult for the results of generative AI teaching to be recognized within the existing system, reducing the motivation of schools and teachers to apply it.

6. Future Development Trends

Future research will shift from short-term effect verification to long-term tracking studies, focusing on the relationship between the duration, frequency, type of generative AI usage and the cognitive development curve of students, identifying the reasonable usage boundaries and cognitive risk critical points. Additionally, a more human-like generative AI teaching system that conforms to the essence of human learning needs to be developed, not making AI more like a teacher, but making AI better at enabling learners to learn how to think [15].

7. Conclusion

This study systematically addressed the core question of how artificial intelligence affects the cognitive development of junior high school students in mathematics. Through a literature review, it was found that generative AI, through visual design, intelligent diagnosis, hierarchical push and real-time interaction, can effectively reduce the cognitive load of abstract concepts and promote the formation of logical thinking; however, the generative AI mechanism itself has shortcomings such as insufficient non-logical cognitive processing and compression of cognitive conflict space, and excessive use can lead to cognitive inertia and weakened independent thinking. The innovation of this study lies in integrating the research on generative AI mathematics education from the perspective of the dual effects of cognitive development. It clearly identifies two key risk dimensions: excessive use and mechanism deficiency, which differ from the previous single paradigm that only focused on the positive effects of technology. The research value lies in that it provides an analytical framework for cognitive-friendly human-machine collaborative design in theory, and offers a reference basis for teachers to clarify the application boundaries of generative AI and avoid the risks of technological alienation in practice. However, there are still limitations. There is a lack of long-term tracking data, and the differences among various generative AI systems have not been differentiated. In the future, longitudinal research needs to be conducted, interpretable cognitive diagnostic models need to be developed, and the adaptive exit mechanism needs to be explored. This will enable generative AI to actively reduce intervention when students' abilities improve, thus leaving room for independent thinking.

References

[1] Liu, J., Sun, D., Sun, J., Wang, J., Yu, Y., & Leung Ho, P. (2025). Designing a generative AI-enabled learning environment for mathematics word problem solving in primary schools: Learning performance, attitudes and interaction. Computers and Education: Artificial Intelligence, 9, 100438. https://doi.org/10.1016/j.caeai.2025.100438

[2] Lu, Y. (2022). How mathematics learning can break away from dependence on repetitive exercises: Personalized teaching based on AI technology [in Chinese]. People’s Education, 11, 42–45.

[3] Chen, Z. H. (2025). From “playing AI” to “understanding AI”: Effective strategies for junior high school students’ artificial intelligence enlightenment education [in Chinese]. Computer Application Abstracts, 41(12), 11–12.

[4] Awang, L. A., Yusop, F. D., & Danaee, M. (2025). Current practices and future direction of artificial intelligence in mathematics education: A systematic review. International Electronic Journal of Mathematics Education, 20(2), em0823.

[5] Li, H. Y., Yang, Y., Qin, Y., Fu, M. X., & Lü, Z. W. (2024). From data to evidence: Student learning diagnostics methods for evidence-based teaching [in Chinese]. Modern Educational Technology, 34(11).

[6] Sun, K. H., Zheng, X. D., & Yang, H. Y. (2025). Design and practice of a generative AI-supported human–machine collaborative precision teaching model [in Chinese]. Digital Education, 11(5).

[7] Liu, Z. Y. (2025). Research on the application of AI-assisted teaching feedback in improving classroom interaction quality in higher education [in Chinese]. Frontiers in Social Sciences, 1(10).

[8] Li-xin, Y., Alwabel, A. S. A., & Mohamad, U. H. (2025). AI-powered education: Transforming teacher–student interactions and advancing sustainable learning practices. European Journal of Education, 60(4). https://doi.org/10.1111/ejed.70351

[9] Xing, W., Kim, T., Song, Y., Li, H., Li, C., & Kim, J. (2026). Unveiling interaction patterns between students and generative AI teachable agent: Focusing on students' agency and AI agents' authority. British Journal of Educational Technology. Advance online publication.

[10] Zhai, C. Y. (2026). Reconstruction of error-diagnosis paradigms and precision intervention for generative AI-enabled logical reasoning literacy in junior high school mathematics [in Chinese]. Chinese Scientific Journal Database (Full-Text Edition): Educational Sciences, 2, 86–89.

[11] Li, J. L. (2024). Practical pathways of the “AI + aesthetic education” cultivation mechanism [in Chinese]. Science & Technology Vision, 14(23), 50–53.

[12] Wang, X. D. (2025). Structured teaching: A cognitive pathway toward deep understanding in mathematics [in Chinese]. Jiangsu Education, 35, 6.

[13] Ji, F. J. (2024). Lazy thinking: ChatGPT and the generative risks of readers’ cognitive inertia [in Chinese]. Journal of Academic Library and Information Science, 42(6), 15–19, 27. http://dx.chinadoi.cn/10.3969/j.issn.1006-1525.2024.06.003

[14] Zhou, X., Teng, D., & Al-Samarraie, H. (2024). The mediating role of generative AI self-regulation on students' critical thinking and problem-solving. Education Sciences, 14(12), 1302. https://doi.org/10.3390/educsci14121302

[15] Richard, P. R., Vélez, M. P., & Van Vaerenbergh, S. (2022). Mathematics education in the age of artificial intelligence: How artificial intelligence can serve mathematical human learning. Canadian Journal of Science, Mathematics and Technology Education, 22(4), 785–805.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.

Open Access