

DEEP LEARNING IN IMPROVING STUDENTS' MATHEMATICAL CRITICAL THINKING: A SYSTEMATIC LITERATURE REVIEW

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Abstrak

Mathematical critical thinking skills are one of the essential competencies that students must have in 21st-century mathematics learning. However, learning practices in schools still tend to be oriented towards procedural mastery and formula memorization, so they are not optimal in developing students' higher-order thinking skills. One approach that is considered relevant to overcome this problem is deep learning, which emphasizes meaningful understanding, interrelationships between concepts, reflection, and the application of knowledge in real contexts. This study aims to analyze the implementation of deep learning in improving students' mathematical critical thinking skills. The research method used is a systematic literature review with a descriptive qualitative approach to relevant national articles. This study reviews 20 research articles obtained from the Google Scholar database with a publication range from 2025 to 2026. The results of the study show that deep learning is able to encourage students to analyze mathematical problems in depth, evaluate solution strategies, and construct logical mathematical arguments. Thus, deep learning has the potential to be an effective approach in improving the quality of mathematics learning.

Keywords: Deep Learning, Mathematics Learning, Mathematical Critical Thinking

INTRODUCTION

The development of education in the 21st century demands a paradigm shift in learning, including in mathematics learning. Mathematics is no longer seen merely as a collection of formulas and mechanistic procedures, but as a means to develop the logical, analytical, and critical thinking skills that students need to deal with various problems in life (Turmuzi et al., 2024; Aini & Nikmatuzzahro, 2025). In this context, critical thinking skills are essential competencies because they enable students to analyze problems, evaluate information, and construct and justify mathematical arguments rationally and systematically (Antara et al., 2024; Sabat et al., 2024). Modern learning emphasizes the mastery of higher-order thinking skills, such as analysis, evaluation, and synthesis, so that in

mathematics learning, students are required to understand concepts in depth, choose the right solution strategies, and reflect on the thinking processes used (Karma et al., 2023; Dewi et al., 2023).

However, various research results show that the mathematical critical thinking skills of Indonesian students are still not optimally developed. National and international assessments, such as PISA and TIMSS, indicate that students still have difficulty solving contextual, non-routine mathematical problems that require high-level reasoning. This condition reflects that mathematics learning in schools does not fully encourage students to think critically, analytically, and reflectively. In general, students tend to be able to solve routine problems, but experience obstacles when

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faced with problems that require deep conceptual understanding and evaluative skills, resulting in a gap between 21st-century competency requirements and classroom learning practices (Mertasari et al., 2023; Bayu et al., 2023).

One factor contributing to low critical thinking skills is the implementation of conventional teacher-centered learning (Mudana et al., 2023; Purwasila et al., 2024). Learning is still dominated by procedural material delivery, an emphasis on memorizing formulas, and an orientation towards achieving the final answer without paying adequate attention to the students' thinking process (Astawan et al., 2023; Rati et al., 2023). This learning pattern reflects surface learning, which emphasizes mastery of algorithms without deep conceptual understanding, resulting in students being poorly trained to analyze problems, evaluate solution strategies, and reflect on the results obtained (Devi & Bayu, 2020).

In response to these issues, deep learning has emerged as a pedagogical approach that emphasizes meaningful learning and the development of conceptual understanding. This approach encourages active student engagement, interconceptual connections, and the application of knowledge in various relevant contexts (Dewi et al., 2025). In mathematics learning, deep learning focuses not only on the final answer, but also on understanding the process, reasoning, and problem-solving strategies. Through this approach, students are trained to connect information, evaluate mathematical arguments, and develop various alternative solutions logically and systematically (Pujawan et al., 2022; Qondias et al., 2022). In addition, deep learning emphasizes the active role of students in constructing knowledge through discussion, contextual problem solving, and reflection, in line with the constructivist view that positions students as active subjects in learning (Chrishanty et al., 2025; Dewi et al., 2025).

Various empirical studies indicate that the implementation of deep learning approaches has considerable potential to improve the quality of mathematics learning.

Previous research has shown that deep learning-oriented instruction can promote active student engagement, strengthen conceptual understanding through meaningful connections between mathematical concepts, and support the development of higher-order thinking skills. In mathematics education, these skills are closely related to students' ability to analyze problems, evaluate solution strategies, and construct logical mathematical arguments, which are essential components of mathematical critical thinking skills. Therefore, the integration of deep learning in mathematics classrooms is considered relevant to address learning practices that still tend to emphasize procedural knowledge and the memorization of formulas.

Nevertheless, several limitations can be identified in previous studies. Most studies on deep learning focus on general learning outcomes or conceptual understanding, while only a limited number explicitly examine its relationship with students' mathematical critical thinking skills. In addition, existing studies are often conducted in different educational contexts and reported individually, resulting in fragmented findings that do not yet provide a comprehensive overview of how deep learning contributes to the development of mathematical critical thinking in mathematics learning.

Based on these limitations, a synthesis of previous research findings is needed to obtain a more integrated understanding of this topic. Therefore, this study conducts a systematic literature review to analyze and synthesize relevant national research on the implementation of deep learning in improving students' mathematical critical thinking skills. The contribution of this article lies in providing a comprehensive overview of existing studies, identifying research trends and gaps, and offering an integrated perspective that can serve as a reference for future research and the development of mathematics learning practices oriented toward deep learning.

METHOD

The research method used in this study is a literature study with a descriptive qualitative approach. This approach was used to collect, analyze, and synthesize various relevant research results regarding the role of deep learning in improving students' mathematical critical thinking over the last three years, namely the period from 2025 to 2026. The research model applied was a Systematic Literature Review (SLR) which aimed to identify, evaluate, and interpret previous research results related to the topic under review.

The research process began with the identification of research topics focusing on deep learning in mathematics learning and its relationship to students' mathematical critical thinking. Next, a literature search was conducted using various online sources such as Google Scholar, ResearchGate, and publish or perish to obtain articles and journals that met the established inclusion criteria. The initial search identified a total of 40 articles consisting of 30 articles from Google Scholar, 5 articles from ResearchGate, and 5 articles from publish or perish. Data collection was carried out by searching for articles using the keywords deep learning, critical thinking, and mathematics learning. The selected articles were then screened based on their relevance to the topic, abstract, and research objectives. During the screening process, several stages of article elimination were conducted. First, duplicate articles were removed, resulting in the exclusion of 5 articles. Second, a title and abstract screening was conducted, which excluded 10 articles that were considered irrelevant to the research topic. Third, a full-text evaluation was conducted, resulting in the exclusion of 5 articles that did not meet the inclusion criteria. After this process, 20 articles were selected as the final sources for in-depth analysis. The data were analyzed thematically by identifying the characteristics of deep learning

implementation and its contribution to the development of students' critical and mathematical thinking skills. After all the literature was collected, the researchers selected the sources based on topic relevance, publication recency, and content suitability. The selected articles were then analyzed in depth to identify the research objectives, methods, and results. The analysis was conducted thematically by grouping each finding according to the main theme of the research so that a systematic synthesis could be carried out.

The research subjects in this study were various scientific articles discussing the application of deep learning and students' mathematical critical thinking. Because this research was literature-based, it did not have a physical location but was based on digital documents. The inclusion criteria for literature selection included articles published in the last three years, containing keywords relevant to the research topic, in the form of full articles, and written in Indonesian or English. Articles were excluded if they were not directly related to mathematics education, did not discuss deep learning or mathematical critical thinking, were not available in full-text form, or were outside the specified publication period. The data obtained was then grouped thematically to facilitate the synthesis of results. The research procedure in this study followed the stages of a Systematic Literature Review, which included identifying and formulating the research problem, planning a literature search through credible online sources, assessing the quality of the selected articles based on the clarity of research objectives, methodological rigor, relevance to the research topic, and the credibility of the findings, extracting data from previous research results, and analyzing and synthesizing the data descriptively. The final result of this process is a conceptual map showing the relationship between the application of deep learning and students' mathematical critical thinking as a basis for developing and evaluating more effective mathematics learning strategies.

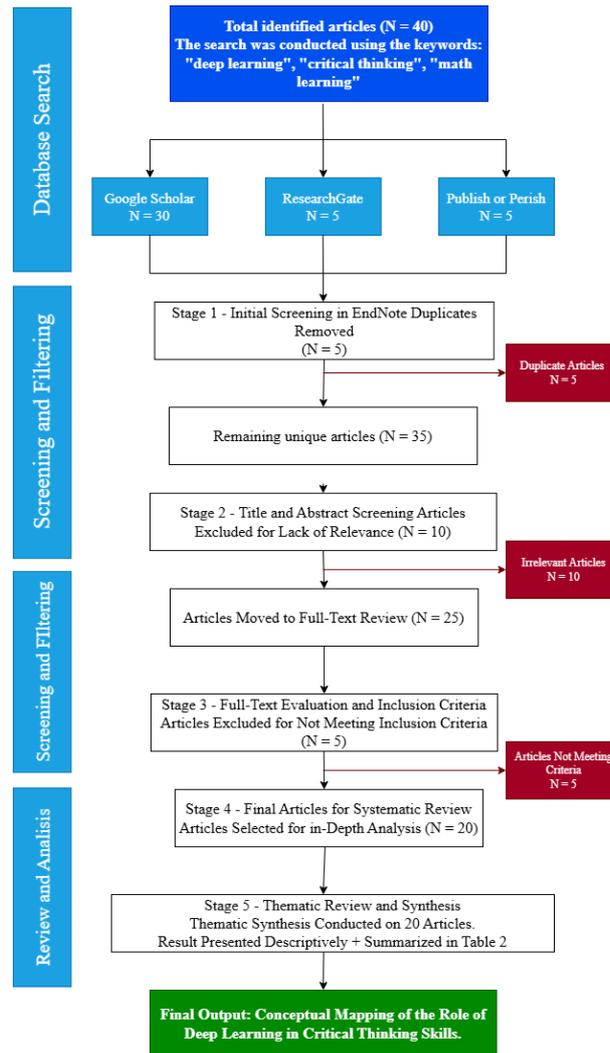


Figure 1. PRISMA Flowchart of Article Search and Selection Process

RESEARCH RESULTS AND DISCUSSION

The results of this study were obtained through a systematic review of 20 national articles discussing the implementation of deep learning and students' mathematical critical thinking skills in mathematics learning. The articles were collected from Google Scholar, ResearchGate, and publish or perish with a publication range of 2025 to 2026 to ensure relevance to the current educational context. The identification and selection of the articles followed predetermined inclusion criteria, including topic relevance, publication recency, and the availability of full-text documents.

To synthesize the findings across the reviewed studies, the analysis was

conducted using a thematic synthesis approach that focuses on identifying recurring patterns, conceptual relationships, and dominant themes related to the implementation of deep learning in mathematics education. Through this approach, the reviewed literature was examined to explore how deep learning principles are implemented in mathematics learning and how these practices contribute to the development of students' mathematical critical thinking skills. The results of the literature analysis are summarized in Table 1, which presents the research methods, theoretical perspectives, and main findings reported in each reviewed study.

Table 1. Characteristics of the Reviewed Studies on Deep Learning in Mathematics Education

No.	(Author, Year)	Research Method	Focus / Indicators Used	Main Findings Related to Mathematical Critical Thinking
1	(Idris et al., 2025)	Quasi-Experiment	Higher Order Thinking Skills (HOTS), critical thinking indicators	The implementation of deep learning that emphasizes exploratory and reflective activities has been proven to improve students' mathematical critical thinking skills, particularly in analyzing problems and evaluating solution strategies.
2	(Amiroh & Putri, 2025)	Descriptive Quantitative	Conceptual understanding, analytical reasoning	Deep learning promotes a deeper understanding of mathematical concepts and improves students' analytical reasoning skills in solving non-routine mathematical problems.
3	(Sasabilla & Nisa, 2026)	Descriptive Qualitative	Deep learning approach, conceptual understanding, reflective thinking	The implementation of deep learning encourages students to actively construct mathematical knowledge through exploration and reflection. This learning approach helps students develop deeper conceptual understanding and improves their ability to analyze mathematical problems critically and formulate logical solutions.
4	(Mailani et al., 2025)	Descriptive Qualitative	Problem solving, reflective thinking indicators	Deep learning-based mathematics learning encourages students to focus on the thinking process, thereby improving their reflective and argumentative abilities, as well as their ability to solve mathematical problems logically and systematically.
5	(Mudjib et al., 2025)	Literature review	Deep learning principles (mindful, meaningful, joyful learning); deep cognitive engagement; learning reflection	Deep learning contributes to strengthening critical thinking processes through reflective activities and deep cognitive engagement, enabling students to analyze mathematical problems in a more conscious, focused, and meaningful way.

No.	(Author, Year)	Research Method	Focus / Indicators Used	Main Findings Related to Mathematical Critical Thinking
6	(Rahayu et al., 2025)	Literature Review	PMRI approach, conceptual understanding, analytical reasoning	The integration of deep learning with the PMRI approach promotes meaningful mathematical learning through contextual problem situations. This approach enhances students' conceptual understanding and strengthens their analytical reasoning, which contributes to the development of students' mathematical critical thinking skills.
7	(Panca & Parisu, 2025)	Literature Review	Higher Order Thinking Skills (HOTS), analysis and evaluation	Deep learning emphasizes active learning processes that focus on conceptual understanding rather than memorization. Through inquiry and discussion activities, students are encouraged to analyze mathematical problems and evaluate different solution strategies, thereby improving their mathematical critical thinking abilities.
8	(Barokah & Mahmudah, 2025)	Literature review	Mindful learning, meaningful learning, joyful learning	Deep learning creates a reflective and meaningful learning environment that supports the development of mathematical critical thinking, particularly in the ability to analyze, reason, and communicate mathematical solutions logically
9	(Wahyudi, 2026)	Quasi-Experiment	Critical thinking indicators: interpretation, analysis, evaluation, inference	The findings show that students who learn through deep learning-based instruction demonstrate higher mathematical critical thinking skills compared to students who experience conventional learning. Deep learning facilitates deeper conceptual processing that enables students to interpret problems accurately, analyze solution strategies, and draw logical conclusions.

No.	(Author, Year)	Research Method	Focus / Indicators Used	Main Findings Related to Mathematical Critical Thinking
10	(Ariani & Sari, 2026)	Quasi-Experiment	Problem Based Learning, reasoning, evaluation, problem solving	The implementation of Problem Based Learning integrated with a deep learning approach significantly improves students' mathematical critical thinking skills. Students become more engaged in analyzing contextual problems, evaluating mathematical solutions, and constructing logical arguments in solving mathematical problems.
11	(Wardani et al., 2025)	Descriptive Qualitative	Deep learning approach, conceptual understanding, active student engagement in mathematics learning	The study examines the implementation of a deep learning approach in elementary mathematics learning. The findings indicate that deep learning encourages students to actively participate in the learning process through interactive activities such as simulations, experiments, and collaborative discussions. This approach helps students develop deeper conceptual understanding and supports the development of critical thinking skills in analyzing mathematical concepts. However, the study also highlights several challenges in implementing deep learning, including limited instructional time and unequal access to technology in schools.

No.	(Author, Year)	Research Method	Focus / Indicators Used	Main Findings Related to Mathematical Critical Thinking
12	(Akbar et al., 2026)	Quasi-Experiment (One Group Pretest–Posttest Design)	Mathematical critical thinking skills, statistical reasoning, deep learning method	The results show that the implementation of the deep learning method significantly improves students' mathematical critical thinking skills. Statistical analysis using the Paired Sample t-Test indicates a significant difference between students' pretest and posttest scores ($p = 0.001$). The average score improvement demonstrates that deep learning effectively enhances students' ability to analyze problems, evaluate mathematical information, and draw logical conclusions. In addition, students show positive responses toward the learning process, indicating that deep learning creates a more engaging and meaningful learning environment.
13	(Arifah et al., 2025)	Quantitative Experimental (Pretest–Posttest Control Group Design)	Deep learning integrated with flipped classroom and digital storytelling; indicators of mathematical critical thinking and mathematical creativity in problem solving	The integration of deep learning with flipped classroom and digital storytelling significantly improves students' mathematical critical thinking and creativity. Students in the experimental group showed better ability in analyzing problems, evaluating solution strategies, and constructing mathematical reasoning compared with the control group.

No.	(Author, Year)	Research Method	Focus / Indicators Used	Main Findings Related to Mathematical Critical Thinking
14	(Makarim et al., 2026)	Literature Review	Deep learning approach in mathematics learning; indicators include critical thinking, problem-solving skills, conceptual understanding, and student engagement	The literature review indicates that deep learning approaches in mathematics instruction promote active student participation, deeper conceptual understanding, and improved critical thinking skills. Instructional strategies such as project-based learning, collaborative learning, and formative assessment support the development of higher-order thinking skills in mathematics learning.
15	(Maharani et al., 2025)	Literature Review	Deep learning in elementary mathematics education; indicators include conceptual understanding, analytical thinking, critical thinking, and meaningful learning engagement	The review shows that the deep learning approach has a positive impact on students' mathematical understanding and fosters critical, creative, and analytical thinking. By emphasizing cognitive, affective, and metacognitive engagement, deep learning supports meaningful mathematics learning and strengthens students' ability to apply concepts in real-life contexts.
16	(Mutmainnah et al., 2025)	Qualitative (Observation and Interview)	Implementation of deep learning in elementary school mathematics learning through interactive activities	Deep learning enhances mathematical critical thinking by encouraging concept analysis, mathematical idea exploration, and active reflection on understanding.
17	(Maulidya et al., 2025)	Qualitative descriptive research	Implementation of deep learning in mathematics learning using interactive learning media (Quizizz); indicators include higher-order thinking skills, student engagement, and conceptual understanding	The implementation of deep learning in mathematics learning encourages active student participation and supports the development of higher-order thinking skills. Interactive digital media help create meaningful learning experiences that improve students' conceptual understanding and support the development of mathematical critical thinking skills.

No.	(Author, Year)	Research Method	Focus / Indicators Used	Main Findings Related to Mathematical Critical Thinking
18	(Kholid et al., 2025)	Systematic Literature Review (PRISMA)	Deep learning in mathematics learning through PBL, inquiry, reflective, and collaborative approaches	Deep learning consistently improves mathematical critical thinking in the aspects of conceptual analysis, metacognition, and interconnections between mathematical concepts.
19	(Dahroni et al., 2025)	Quantitative Experiment	Deep learning in function composition material through the stages of <i>mindful learning</i> , <i>meaningful learning</i> , and <i>joyful learning</i> emphasizes conceptual understanding and active student involvement.	Deep learning contributes to mathematical critical thinking, particularly in conceptual understanding and mathematical reasoning, by encouraging students to understand the relationships between functions in a mindful and meaningful way, thereby reducing conceptual errors in problem solving.
20	(Ratnasari et al., 2025)	Descriptive Analytical	Deep Learning as a learning approach that emphasizes thinking, engagement, and understanding	Conceptually, deep learning supports mathematical critical thinking through cognitive engagement and meaning-making, not through direct measurement of critical abilities, but through learning that encourages students to understand the reasons, meanings, and purposes of the mathematical concepts.

To gain deeper insight into the synthesized findings, a thematic analysis was conducted on the reviewed literature to identify dominant patterns, pedagogical implications, and potential research gaps in the implementation of deep learning in mathematics education. The analysis reveals a recurring pattern in the application of deep learning principles that emphasize meaningful engagement with mathematical concepts through problem-based activities, non-routine problem solving, collaborative discussion, and reflective learning processes.

Various studies also employ diverse indicators to measure students'

mathematical critical thinking, including Higher Order Thinking Skills (HOTS), analytical reasoning, reflective thinking, evaluation of problem-solving strategies, and mathematical argumentation. These indicators represent key cognitive processes involved in higher-level mathematical reasoning.

However, several limitations remain evident in the existing literature. Many studies rely on short-term interventions and focus primarily on immediate learning outcomes, resulting in limited longitudinal evidence regarding the sustainability of mathematical critical thinking development. In addition, only a small number of studies

discuss contextual factors such as teacher readiness and instructional capacity in designing deep learning environments that explicitly support critical thinking development.

A summary of the main discussion themes, implications, and opportunities for further research identified through this synthesis is presented in Table 2.

Table 2. Summary of Discussion Topics and Opportunities for Further Study

No.	Main Discussion Themes Found in the Reviewed Articles	Analysis of Implications and Limitations	Opportunities for Further Research
1	Implementation of Deep Learning in Mathematics Learning	Most of the reviewed studies emphasize that the implementation of deep learning encourages meaningful engagement in mathematics learning. Learning environments designed using deep learning principles promote active student participation, reflective thinking, and deeper exploration of mathematical concepts. These learning conditions support students in analyzing mathematical problems and developing more sophisticated reasoning processes. However, many studies still describe the implementation of deep learning at a conceptual level without providing detailed instructional frameworks or systematic learning designs that can be consistently applied in different classroom contexts.	Future research should focus on developing structured pedagogical models that clearly operationalize deep learning principles in mathematics learning. Empirical studies are also needed to examine how different instructional designs based on deep learning influence specific dimensions of students' mathematical critical thinking.
2	Conceptual Understanding as the Foundation of Mathematical Critical Thinking	Several reviewed studies highlight conceptual understanding as a key element supporting the development of students' mathematical critical thinking. Deep learning environments encourage students to explore relationships between mathematical ideas, reflect on problem-solving strategies, and construct meaningful conceptual connections. These processes enable students to interpret problems more analytically and evaluate alternative solutions. However, most studies examine conceptual understanding and critical thinking descriptively, and the causal relationship between	Further research is needed to examine the causal mechanisms linking conceptual understanding and mathematical critical thinking using experimental or longitudinal research designs. Structural modeling approaches could also be applied to explore how conceptual understanding mediates the development of higher-order thinking in mathematics learning.

No.	Main Discussion Themes Found in the Reviewed Articles	Analysis of Implications and Limitations	Opportunities for Further Research
		these two constructs has not been thoroughly investigated through rigorous empirical designs..	
3	Indicators Used to Measure Mathematical Critical Thinking	The reviewed studies employ a variety of indicators to assess students' mathematical critical thinking skills, including Higher Order Thinking Skills (HOTS), analytical reasoning, reflection, strategy evaluation, and mathematical argumentation. These indicators reflect important cognitive processes involved in mathematical reasoning and problem solving. Nevertheless, considerable variation exists in how these indicators are defined and operationalized across different studies, resulting in a lack of consistency in measuring mathematical critical thinking within deep learning contexts.	Future research should aim to develop a more comprehensive and standardized framework for assessing mathematical critical thinking in mathematics education. Such frameworks would help researchers and educators measure critical thinking more consistently across different learning contexts and instructional approaches..
4	Integration of Deep Learning with Innovative Learning Approaches	Many studies indicate that deep learning is frequently implemented in combination with innovative instructional approaches such as problem-based learning, inquiry-based learning, contextual learning, and technology-supported learning environments. These approaches provide opportunities for students to engage in authentic problem solving and collaborative learning processes that stimulate deeper cognitive engagement. However, most existing studies focus on short-term classroom interventions and provide limited evidence regarding the long-term effectiveness of these integrated approaches.	Future research should investigate the long-term impact of integrating deep learning with various instructional models. Longitudinal studies and large-scale experimental research are needed to examine the sustainability of students' critical thinking development in mathematics learning.
5	Reflective and Exploratory Learning Processes in Mathematics Learning	Several studies highlight the importance of reflective and exploratory learning activities in supporting students' deeper engagement with mathematical ideas. Through reflective	Future research should explore instructional strategies that systematically incorporate reflective learning and

No.	Main Discussion Themes Found in the Reviewed Articles	Analysis of Implications and Limitations	Opportunities for Further Research
		discussions, collaborative problem solving, and exploration of non-routine mathematical tasks, students are encouraged to analyze their reasoning processes and evaluate alternative strategies. These learning experiences contribute to the development of analytical reasoning and metacognitive awareness. However, reflective learning processes are not always systematically integrated into mathematics instruction and often depend on the teacher's instructional approach.	exploratory problem-solving activities in mathematics classrooms. Studies examining the role of metacognitive reflection in strengthening students' mathematical critical thinking would also provide valuable insights.
6	Methodological Limitations and Research Gaps in Existing Studies	The majority of reviewed studies employ short-term research designs with relatively small sample sizes and limited intervention periods. As a result, empirical evidence regarding the long-term sustainability of deep learning in developing mathematical critical thinking remains limited. In addition, relatively few studies examine contextual factors such as teacher readiness, instructional design competencies, and institutional support for implementing deep learning in mathematics education.	Future studies should adopt more rigorous research designs, including longitudinal studies, mixed-method approaches, and large-scale experimental research. Investigating teacher professional development and institutional support systems would also provide important insights into the effective implementation of deep learning in mathematics education.

Based on the synthesis presented in Table 2, a conceptual relationship can be identified between the implementation of deep learning and the development of students' mathematical critical thinking. The reviewed studies consistently indicate that deep learning environments encourage students to engage more deeply with mathematical concepts through exploration, reflection, and problem-solving activities. These learning experiences support the development of conceptual understanding,

which plays an important role in strengthening higher-order cognitive processes such as analytical reasoning, evaluation of solution strategies, reflective thinking, and mathematical argumentation.

The synthesis also suggests that the effectiveness of deep learning in promoting mathematical critical thinking is influenced by instructional design and the learning context in which it is implemented. Approaches such as problem-based learning, inquiry activities, and collaborative

discussions are frequently integrated to create learning environments that stimulate deeper cognitive engagement.

Overall, the reviewed literature indicates that deep learning contributes to the development of mathematical critical thinking through the reinforcement of conceptual understanding and higher-order reasoning processes. However, further

The Role of Deep Learning in Developing Mathematical Reasoning

A synthesis of the reviewed studies indicates that deep learning plays a crucial role in strengthening students' mathematical reasoning by fostering deeper conceptual engagement and reflective thinking processes. Unlike procedural learning that emphasizes the application of formulas and routine algorithms, deep learning encourages students to interpret mathematical concepts, analyze relationships between ideas, and justify their reasoning through analytical and reflective processes. These cognitive activities form the foundation of higher-order mathematical reasoning and critical thinking in mathematics learning (Mudjib et al., 2025; Maharani et al., 2025; Ratnasari et al., 2025).

Across the reviewed empirical studies, a consistent pattern emerges indicating that deep learning environments promote more complex reasoning processes when students are engaged in exploratory activities and non-routine problem solving. For instance, Idris et al. (2025) and Ariani and Sari (2026) report that learning environments integrating deep learning with problem-based learning encourage students to analyze contextual mathematical problems, evaluate alternative solution strategies, and construct logical arguments. Similarly, experimental studies by Wahyudi (2026) and Akbar et al. (2026) demonstrate that deep learning significantly improves students' ability to interpret mathematical problems, analyze information systematically, and draw logical conclusions. These findings suggest that deep learning facilitates reasoning development by shifting learning from procedural execution toward analytical

research is still needed to examine this relationship more systematically, particularly through longitudinal studies and broader investigations of instructional factors that support the sustainable development of students' mathematical critical thinking.

problem interpretation and strategic evaluation.

Another important pattern identified in the reviewed literature is the role of conceptual understanding as a central mechanism connecting deep learning and mathematical reasoning. Several studies emphasize that deep learning promotes the construction of meaningful conceptual relationships that enable students to reason more effectively about mathematical structures and problem situations. Amiroh and Putri (2025) demonstrate that deeper conceptual understanding supports students in identifying relationships among mathematical ideas when solving non-routine problems. Similar observations are reported by Sasabilla and Nisa (2026) and Wardani et al. (2025), who highlight that exploration, collaborative discussion, and reflective activities in deep learning environments facilitate the active construction of mathematical knowledge and strengthen students' ability to analyze mathematical situations critically.

In addition, the reviewed literature highlights the importance of deep learning principles particularly mindful learning, meaningful learning, and joyful learning in supporting students' reasoning processes. Dahroni et al. (2025) show that when students engage in mindful and meaningful learning stages, they demonstrate stronger conceptual reasoning and fewer conceptual errors in solving mathematical problems. Likewise, Barokah and Mahmudah (2025) emphasize that meaningful and reflective learning environments encourage students to articulate their reasoning, evaluate solution strategies, and refine their understanding through discussion and reflection.

From a pedagogical perspective, the effectiveness of deep learning in developing

mathematical reasoning is strongly influenced by instructional design and teacher facilitation. Studies by Rahayu et al. (2025), Kholid et al. (2025), and Makarim et al. (2026) indicate that learning environments incorporating inquiry-based activities, contextual problem situations, collaborative discussions, and reflective evaluation provide more opportunities for students to engage in analytical reasoning and conceptual exploration. However, despite these promising findings, the literature also reveals several limitations,

Contribution of Deep Learning to Mathematical Critical Thinking Skills

A synthesis of the reviewed studies indicates that deep learning contributes significantly to the development of students' mathematical critical thinking skills through both direct instructional effects and indirect cognitive mechanisms. In mathematics education, mathematical critical thinking generally refers to students' ability to analyze problems, evaluate solution strategies, reflect on their reasoning processes, and construct logical and evidence-based mathematical arguments.

Several empirical studies provide direct evidence that the implementation of deep learning improves students' mathematical critical thinking. For example, Idris et al. (2025) demonstrate that deep learning integrated with problem-based learning activities encourages students to analyze mathematical problems and evaluate alternative solution strategies. Similar findings are reported by Ariani and Sari (2026), who found that students engaged in deep learning-based instruction show stronger abilities in evaluating contextual mathematical solutions and constructing logical arguments. Experimental studies conducted by Wahyudi (2026) and Akbar et al. (2026) further confirm that deep learning significantly improves students' abilities to interpret mathematical problems, analyze information systematically, and draw logical conclusions compared with conventional learning approaches.

Beyond these direct instructional effects, several studies indicate that the contribution of deep learning to

particularly regarding teacher readiness and the availability of instructional frameworks that explicitly integrate deep learning principles with indicators of mathematical reasoning and critical thinking. As highlighted in the thematic synthesis presented in Table 2, these limitations suggest the need for more systematic pedagogical models that support the sustainable development of mathematical reasoning through deep learning environments.

mathematical critical thinking often occurs through indirect cognitive processes, particularly through the strengthening of conceptual understanding and deeper cognitive engagement. Ratnasari et al. (2025) explain that deep learning encourages students to understand the meaning and purpose of mathematical concepts rather than merely applying procedures. This process supports the development of analytical and evaluative thinking abilities that form the core components of mathematical critical thinking. Similar conclusions are highlighted in studies by Amiroh and Putri (2025) and Sasabilla and Nisa (2026), which show that deeper conceptual understanding enables students to analyze relationships between mathematical ideas and apply them in solving non-routine problems.

In addition, several literature reviews and synthesis studies emphasize that deep learning environments support the development of higher-order thinking through reflective learning activities, conceptual integration, and collaborative knowledge construction. For instance, Mudjib et al. (2025), Maharani et al. (2025), and Makarim et al. (2026) highlight that learning designs emphasizing exploration, reflection, and conceptual understanding provide opportunities for students to engage in deeper reasoning processes. Likewise, Kholid et al. (2025) conclude that deep learning approaches integrated with inquiry, problem-based learning, and collaborative activities consistently support the development of mathematical critical thinking through conceptual analysis,

metacognition, and connections between mathematical ideas.

Another important finding emerging from the reviewed literature is the diversity of indicators used to measure mathematical critical thinking, including Higher Order Thinking Skills (HOTS), analytical reasoning, reflective thinking, evaluation of solution strategies, and mathematical argumentation. Although there is no universally standardized framework for assessing mathematical critical thinking, these indicators consistently emphasize higher-order cognitive processes that are facilitated through meaningful and reflective learning experiences.

Discussion

Based on the synthesis of the reviewed literature, deep learning plays a significant role in developing students' mathematical reasoning and critical thinking skills. Unlike traditional learning approaches that emphasize procedural execution and memorization, deep learning promotes deeper cognitive engagement, conceptual understanding, and reflection on the reasoning process. Through this approach, students are encouraged not only to apply mathematical procedures but also to understand the underlying concepts and justify their solutions logically within meaningful learning contexts.

One of the key mechanisms explaining the effectiveness of deep learning in developing mathematical reasoning is students' engagement in higher-order cognitive activities. Several empirical studies indicate that learning environments integrating deep learning with non-routine problem solving, problem-based learning, and exploratory activities encourage students to analyze mathematical situations, evaluate alternative solution strategies, and construct logical arguments (Idris et al., 2025; Ariani & Sari, 2026; Wahyudi, 2026). Experimental findings further show that students exposed to deep learning-based instruction demonstrate stronger abilities in interpreting mathematical problems, analyzing information systematically, and drawing logical conclusions compared with

However, as highlighted in the thematic synthesis presented in Table 2, several research gaps remain evident in the current literature. Most studies employ short-term research designs and focus primarily on immediate learning outcomes, resulting in limited longitudinal evidence regarding the sustainability of students' mathematical critical thinking development. In addition, challenges related to teacher readiness, instructional design competence, and the development of standardized assessment instruments for mathematical critical thinking suggest the need for further research to strengthen the implementation of deep learning in mathematics education.

students experiencing conventional learning (Akbar et al., 2026).

From a theoretical perspective, these findings are consistent with Piaget's constructivist theory, which emphasizes that knowledge develops through processes of assimilation and accommodation within learners' cognitive structures. When students encounter challenging mathematical problems that cannot be solved using routine procedures, cognitive disequilibrium occurs, motivating them to reorganize their conceptual understanding. Deep learning environments particularly those emphasizing mindful and meaningful learning create opportunities for such cognitive restructuring by encouraging exploration, reflection, and conceptual connections (Dahroni et al., 2025; Barokah & Mahmudah, 2025).

In addition, deep learning aligns with Vygotsky's sociocultural perspective, which highlights the importance of social interaction in the development of higher-order cognitive abilities. Many of the reviewed studies indicate that deep learning is frequently implemented through collaborative learning, group discussions, and reflective dialogue. These interactions enable students to articulate their reasoning, evaluate alternative perspectives, and refine their understanding through feedback from peers and teachers. Such collaborative processes create a zone of proximal

development in which students can achieve higher levels of reasoning and critical thinking than they could independently (Rahayu et al., 2025; Kholid et al., 2025).

Reflection also emerges as a central component of deep learning that contributes significantly to the development of mathematical critical thinking. Reflective activities allow students to evaluate their problem-solving strategies, identify conceptual errors, and reconsider the reasoning underlying their solutions. Studies indicate that learning designs incorporating reflection and metacognitive evaluation strengthen students' ability to analyze mathematical problems and justify their reasoning logically (Mailani et al., 2025; Mutmainnah et al., 2025). In this sense, critical thinking develops not merely as a learning outcome but as a continuous cognitive process that evolves during meaningful learning experiences.

However, the thematic synthesis presented in Table 2 also reveals several limitations in the existing literature. Most studies rely on short-term research designs and relatively limited sample sizes, resulting in insufficient evidence regarding the long-term sustainability of mathematical reasoning and critical thinking development through deep learning. In addition, although various indicators of mathematical critical thinking such as Higher Order Thinking Skills (HOTS), analytical reasoning, strategy evaluation, and mathematical argumentation have been used across studies, a standardized framework for assessing these skills within deep learning contexts remains underdeveloped.

CONCLUSION

Based on the results of a systematic review of twenty selected studies, this study concludes that deep learning plays a significant role in improving students' mathematical critical thinking skills. Deep learning promotes deeper cognitive engagement, meaningful conceptual understanding, reflection on thinking processes, and the integration of mathematical concepts. Through these characteristics, students are encouraged not

Another important factor highlighted in the literature is the role of teachers in facilitating effective deep learning environments. Studies indicate that teachers' ability to design meaningful, reflective, and cognitively challenging learning activities strongly influences the development of students' reasoning and critical thinking skills (Mudjib et al., 2025; Makarim et al., 2026). Nevertheless, challenges related to teacher readiness, professional training, and the availability of structured instructional design guidelines remain significant barriers to the broader implementation of deep learning in mathematics education.

Overall, the findings of this systematic review reinforce the view that deep learning represents a relevant and strategic pedagogical approach for mathematics education in the twenty-first century. By promoting meaningful engagement, conceptual understanding, and reflective thinking, deep learning supports the development of higher-order cognitive abilities, particularly mathematical reasoning and critical thinking. Consequently, integrating deep learning into mathematics instruction offers a promising pathway for addressing persistent challenges such as low student engagement and superficial conceptual understanding. Future research should therefore focus on developing comprehensive instructional frameworks, strengthening teacher professional development, and conducting longitudinal studies to examine the long-term impact of deep learning on students' mathematical critical thinking development.

only to apply mathematical procedures but also to analyze problems, evaluate solution strategies, and construct logical mathematical arguments.

The reviewed literature indicates that the implementation of deep learning through approaches such as problem-based learning, inquiry-based learning, and contextual learning creates meaningful cognitive challenges that stimulate higher-order thinking processes. In these learning

environments, students are actively involved in identifying problems, exploring alternative solutions, evaluating the validity of their reasoning, and reflecting on the effectiveness of their strategies. These processes contribute directly to strengthening students' mathematical critical thinking skills while also fostering metacognitive awareness, active learning engagement, and reflective thinking.

However, the findings of this review also reveal several limitations in the existing literature. Most of the studies focus on short-term learning outcomes, resulting in limited empirical evidence regarding the long-term development of mathematical critical thinking skills. In addition, teachers' readiness to design and implement deep learning strategies that explicitly target critical thinking development remains a challenge in many educational contexts.

Therefore, teachers are encouraged to integrate deep learning principles into mathematics instruction in order to promote meaningful conceptual understanding and critical thinking among students. Educational institutions may use these findings as a basis for curriculum development and teacher professional training. Future research is recommended to investigate the long-term implementation of deep learning, develop more standardized frameworks for assessing mathematical critical thinking, and explore its effectiveness across different educational levels and learning contexts.

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