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Effectiveness of Artificial Intelligence as a Learning Medium on Logical-Mathematical Thinking Skills and Self-Regulated Learning Among Senior Secondary Students: A Systematic Literature Review

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ABSTRACT

The low mathematical logical thinking ability of Indonesian students is reflected in Indonesia's 2022 PISA score of 366, which falls significantly below the OECD average of 472, indicating weaknesses in students' capacity to draw inferences, recognize patterns, construct arguments, and derive systematic conclusions. This study aims to synthesize empirical evidence regarding the effectiveness of Artificial Intelligence (AI) on both competencies, while identifying the types of technology, implementation designs, and moderating factors that influence its impact. A Systematic Literature Review (SLR) was conducted following the PRISMA 2020 guidelines, with searches performed on Google Scholar using PICOS-based keywords structured with Boolean AND/OR operators, restricted to publications from 2024 to 2026. Study selection was conducted independently by two researchers, with inter-rater reliability maintained through Cohen's Kappa. Of 538 initially identified articles, 15 final articles from eight countries were retained following deduplication, screening, and quality assessment using MMAT, RoB 2.0, and NOS. AI technologies were classified into five categories: generative AI, Intelligent Tutoring Systems, adaptive learning systems, educational chatbots, and AI-based Learning Management Systems. Results indicate that AI consistently exerts a positive influence on self-regulated learning through adaptive feedback and metacognitive support, and on mathematical logical thinking ability through its role as a cognitive partner. However, its effectiveness is conditional, necessitating that mathematics teachers integrate AI within structured instructional designs incorporating formative feedback, graduated scaffolding, and metacognitive reflection facilitation.

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Introduction

The mathematical thinking ability of Indonesian students remains a serious challenge in the landscape of education to this day. The 2022 PISA data recorded Indonesia's mathematics literacy score at 366, considerably below the OECD average of 472. This figure reflects that students' capacity for logical and analytical reasoning in solving mathematical problems still requires substantial improvement. One of the contributing factors is the persistent dominance of conventional, passive, and uniform instructional approaches that are unable to respond to the diverse cognitive needs of individual students. This condition becomes particularly urgent at the senior secondary school level, as students at this stage are expected to have entered the formal operational stage of cognitive development (Piaget, 1972), whereby abstract and logical reasoning abilities should develop optimally. Furthermore, the Merdeka Belajar curriculum demands the mastery of higher-order thinking skills, and the strategic position of senior secondary school as a transitional phase toward higher education makes intervention at this level of long-term academic significance.

Within this context, two competencies emerge as critically important to be developed simultaneously: mathematical logical thinking ability and self-regulated learning. Mathematical logical thinking ability encompasses four primary indicators, namely proportional, probabilistic, correlational, and combinatorial thinking (Novaliyosi, 2018), which have been empirically demonstrated to be improvable through structured and sequential instructional approaches (Novaliyosi et al., 2019). Self-regulated learning (SRL), on the other hand, refers to an active process in which students set their own learning goals, monitor their progress, and evaluate their learning outcomes independently (Zimmerman, 2000). These two competencies are not mutually exclusive. Students who demonstrate strong self-regulatory capacity tend to exhibit greater persistence when confronted with complex mathematical problems, which in turn fosters the development of logical reasoning. Although studies examining both competencies have been gradually growing, the majority remain fragmented and have yet to integrate both variables within a unified analytical framework.

The advancement of artificial intelligence (AI) technology opens promising new avenues in mathematics education. It is important to clarify that AI in this review does not refer to a single technology, but rather encompasses five distinct categories: generative AI such as ChatGPT and Google Gemini, intelligent tutoring systems (ITS), adaptive learning systems, learning analytics, and educational chatbots. Theoretically, AI has the potential to influence mathematical logical thinking through three primary mechanisms: adaptive scaffolding that calibrates cognitive challenges in accordance with students' zones of proximal development (Vygotsky, 1978), formative feedback that promotes metacognitive reflection, and learning personalization that enables students to construct understanding at their own cognitive pace. Together, these mechanisms have the potential to create learning conditions that are conducive to the simultaneous development of mathematical logical thinking and self-regulated learning among senior secondary school students.

A growing body of empirical evidence lends support to this potential. Ng et al. (2024), Mehmood et al. (2025), and Adilah et al. (2025) reported positive effects of AI on self-regulated learning among senior secondary school students, while Assagaf & Subekti (2025) and Putri et al. (2025) confirmed AI's effectiveness in enhancing logical and critical mathematical thinking. Nevertheless, not all findings are consistently positive. Bastani et al. (2025) cautioned that in the absence of appropriate pedagogical design, AI use may undermine the depth of long-term learning. Khusna & Fadli (2025) also identified the risk of excessive AI dependency, which may erode students' intrinsic motivation. These inconsistencies in findings suggest that the

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effectiveness of AI is highly contingent upon how it is designed and implemented, thereby necessitating a more systematic synthesis to comprehend its overall impact.

Despite the accumulating evidence, existing systematic reviews still contain fundamental limitations. Wang & Fan (2025) conducted a meta-analysis of ChatGPT's impact in education, yet their review was cross-level and cross-subject in nature without accounting for the distinct context of mathematics at the senior secondary level. Holman et al. (2025) examined intelligent tutoring systems in mathematics but focused exclusively on cognitive outcomes without incorporating the dimension of self-regulation. Létourneau et al. (2025) reviewed adaptive learning systems but did not integrate self-regulated learning and mathematical logical thinking simultaneously. Awang et al. (2025) and Munawaroh et al. (2025) addressed AI in education broadly, without specifying the relevant educational level or subject matter. In sum, prior reviews have generally examined variables in isolation, lacked specificity to the context of senior secondary school mathematics, and have not systematically classified AI technologies based on their functional characteristics.

Building upon these limitations, three research gaps warrant attention. First, no systematic review has yet synthesized the effects of AI on both self-regulated learning and mathematical logical thinking among senior secondary school students in an integrated manner. Second, there is no systematic classification of the differential effectiveness of various AI types within the specific context of senior secondary school mathematics. Third, moderating factors such as pedagogical design, duration of intervention, and student characteristics have not been comprehensively analyzed within a unified synthesis framework. Accordingly, this study aims to: (1) synthesize the effects of AI on self-regulated learning among senior secondary school students; (2) analyze the effects of AI on mathematical logical thinking among senior secondary school students; and (3) identify the types of AI technology and the moderating factors that influence their effectiveness. The research questions are formulated as follows: (1) What types of AI are employed in studies examining both variables? (2) How does AI influence self-regulated learning among senior secondary school students? (3) How does AI influence mathematical logical thinking among senior secondary school students? (4) What moderating factors influence the effectiveness of AI in senior secondary school mathematics learning?

Method

Research Design

This study employs a Systematic Literature Review (SLR) approach aimed at identifying, evaluating, and synthesizing empirical findings related to the use of Artificial Intelligence (AI) in mathematics learning among senior secondary school students. The review process adheres to the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and reproducibility. Data synthesis was conducted narratively using a thematic synthesis approach based on the framework proposed by Thomas & Harden (2008), given the heterogeneity of research designs across the included studies, which precluded quantitative meta-analysis.

Inclusion and Exclusion Criteria

The unit of analysis in this study consists of peer-reviewed articles systematically selected based on predefined inclusion and exclusion criteria using the PICOS (Population, Intervention, Comparison, Outcome, Study design) framework. Literature searches were conducted across one academic database, namely Google Scholar. Inclusion and exclusion criteria were established prior to the search process, encompassing components of population, intervention, comparison, outcome, and study design, as well as considerations of publication language, year range, and methodological quality. Articles that did not meet the minimum quality threshold based on MMAT, RoB 2.0, or NOS according to the respective study design were excluded from the final analysis. A detailed overview of the inclusion and exclusion criteria is presented in Table 1.

Table 1. Inclusion and Exclusion Criteria Based on the PICOS Framework

PICOS Component	Inclusion Criteria	Exclusion Criteria
Population (P)	Senior secondary school students (ages 15–18) in mathematics learning contexts	Primary, middle school, or university students; non-mathematics subjects
Intervention (I)	Use of AI (chatbots, Intelligent Tutoring Systems, adaptive AI, AI in PBL) as a mathematics learning medium	Non-AI digital technologies (general e-learning, calculators); AI tools without a mathematics learning context
Comparison (C)	Control group (conventional instruction) or comparisons between AI types	No comparison group or context; studies without a control group are not automatically excluded if substantively relevant
Outcome (O)	Self-Regulated Learning (SRL) and/or mathematical logical thinking ability in senior secondary school students	Purely affective variables (e.g., anxiety) without links to SRL or logical thinking; procedural learning outcomes alone
Study Design (S)	Empirical studies: experimental, quasi-experimental, correlational, mixed methods, case studies with primary data	Opinion pieces, editorials, non-systematic literature reviews, studies without primary empirical data
Language	Indonesian and English	Languages other than Indonesian and English
Year Range	2024–2026	Prior to 2024
Methodological Quality	Meets the minimum quality threshold of MMAT, RoB 2.0, or NOS (according to study design)	Does not meet the minimum methodological quality threshold

Instrument

The instruments used in this study consist of three main components. First, a title and abstract screening form was used to rapidly assess articles for topical relevance prior to full-text review. Second, a structured data extraction form was used to systematically record information from each eligible article, including article identifiers (author, year, journal), research design, type of AI technology employed, variables measured, measurement instruments used in the primary studies, and key findings. Third, methodological quality appraisal tools were applied according to each study's design: (a) the Mixed Methods Appraisal Tool (MMAT) for mixed methods and qualitative studies; (b) the Risk of Bias 2.0 (RoB 2.0) tool for randomized controlled trials (RCTs); and (c) the Newcastle-Ottawa Scale (NOS) for observational and quasi-experimental studies. Minimum quality thresholds were established as follows: a score of ≥50% on the MMAT, a rating of "low risk" or "some concerns" on RoB 2.0, and a score of ≥5 out of 9 stars on the NOS. Articles failing to meet the applicable threshold were excluded from the final analysis.

Search Strategy and Data Collection

Data collection was carried out through a systematic literature search on Google Scholar using a combination of PICOS-based search strings, including: "artificial intelligence", "AI", "intelligent tutoring system", "chatbot", combined with "mathematics learning", "self-regulated

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learning", "kemandirian belajar", "logical thinking", and "kemampuan berpikir logis matematis". Searches were conducted in both Indonesian and English using Boolean operators (AND, OR), restricted to the publication years 2024–2026.

Study Selection

The article selection process was carried out in sequential stages in accordance with the PRISMA 2020 guidelines and was conducted independently by two reviewers to minimize selection bias. A summary of the number of articles at each selection stage is presented in Table 2.

Table 2. Article Selection Process

Stage	Description	n
Identification	Total records retrieved (Google Scholar, 5 search strings)	538
Deduplication	Duplicate records removed	88
	Records remaining after deduplication	450
Screening	Records excluded based on title and abstract screening	390
	Records retained for full-text eligibility assessment	60
Eligibility	Records excluded after full-text review	45
Inclusion	Final articles included in analysis	15

At the eligibility stage, 45 articles were excluded after full-text review for the following reasons: (a) population was not senior secondary school students (n=15); (b) intervention was not AI-based (n=12); (c) outcome variables did not meet inclusion criteria (n=10); (d) non-empirical research design (n=5); and (e) failure to meet the minimum methodological quality threshold based on MMAT, RoB 2.0, or NOS appraisal (n=3). A total of 15 articles met all inclusion criteria and proceeded to structured data extraction, covering article identifiers, study design, type of AI technology, variables measured, and key findings.

Data Analysis

Data analysis was conducted qualitatively through thematic synthesis following the framework of Thomas & Harden (2008), aimed at identifying patterns, themes, and relationships across research findings. The thematic synthesis process was carried out in three phases. The first phase involved line-by-line coding, in which descriptive codes were assigned to each relevant unit of meaning extracted from the findings, discussion, and conclusion sections of the included articles, without further interpretation at this stage. The second phase involved the development of descriptive themes, whereby codes sharing conceptual similarity were grouped into themes that remained close to the original data, reflecting what the primary studies reported. The third phase involved the development of analytical themes, in which a deeper interpretive analysis of the descriptive themes was conducted to generate understanding that extended beyond the content of individual articles, identifying cross-study patterns, contradictions in findings, and substantive implications regarding the use of AI for self-regulated learning and mathematical logical thinking ability among senior secondary school students. In addition, descriptive analysis was performed to map the distribution of AI technology types, research designs, and variables examined across the final set of included articles.

Research Findings and Discussion

To provide a more systematic empirical overview of the influence of Artificial Intelligence (AI) in mathematics learning, particularly regarding the self-regulated learning and logical-mathematical thinking ability of senior high school students, a review of various prior studies with diverse research designs and AI technologies was conducted. In general, the findings consistently indicate that AI yields positive effects on students' cognitive abilities and self-regulation, especially when integrated with appropriate instructional models, although there is potential for negative outcomes such as dependency when not accompanied by optimal pedagogical guidance. A summary of these research findings is presented in the following Table 3.

Table 3. Summary of Selected Studies on AI Integration in Senior High School Mathematics Learning (2024–2026)

No.	Author & Year	Country	Design	AI Type	Dependent Variable	Key Finding
1.	Ardiansyah & Wulandari (2026)	Indonesia	Case Study	Personal AI Tutor	Mathematics learning motivation	AI as a personal tutor increased senior high school students' motivation in mathematics learning
2.	Assagaf & Subekti (2025)	Indonesia	Correlational	Digital/AI Media	Logical-mathematical thinking	AI-based digital media effectively improved students' logical-mathematical thinking ability
3.	Elfani et al. (2025)	Indonesia	Experimental	Deep Learning AI	Mathematical critical thinking	Deep learning-based AI had a significant effect on students' mathematical critical thinking ability
4.	Mardhatillah et al. (2025)	Indonesia	Empirical	Personalization AI	Mathematics & science learning	AI for learning personalization positively increased student engagement and learning outcomes
5.	Mehmood et al. (2025)	Pakistan	Experimental	AI Metacognitive Tools	Self-Regulated Learning (SRL)	AI-assisted metacognitive strategies significantly improved senior high school students' SRL ($p < 0.05$)
6.	Wardhani et al. (2025)	Indonesia	Empirical	AI (Society 5.0)	Senior high school mathematics learning	AI had a positive impact on senior high school mathematics learning in the Society 5.0 era
7.	Ng et al. (2024)	Hong Kong	Quasi-Experimental	AI Chatbot (ChatGPT)	Self-Regulated Learning (SRL)	ChatGPT-based chatbot significantly improved students' SRL, engagement, and motivation compared to rule-based AI
8.	Adilah et al. (2025)	Indonesia	Quantitative Survey	LMS-based AI	Self-regulated learning & learning effectiveness	AI-based learning had a significant effect on the effectiveness and self-regulated learning of Grade X senior high school students
9.	Chau et al. (2025)	Vietnam	Conceptual	Personal AI Chatbot	Problem-solving & mathematical critical thinking	AI chatbot with adaptive feedback improved mathematical problem-solving competence and critical thinking

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No.	Author & Year	Country	Design	AI Type	Dependent Variable	Key Finding
10.	Tashtoush et al. (2025)	Jordan	Empirical Study	AI Techniques	Mathematical critical thinking & attitude toward mathematics	AI techniques contributed to developing students' mathematical critical thinking ability and positive attitudes toward mathematics
11.	Alatoai & Alshahri (2025)	Saudi Arabia	Mixed-method	Various AI Learning Support Tools	Self-Regulated Learning (SRL)	Produced a valid and reliable instrument (AI-SSRSML) with 6 AI-assisted SRL factors applicable across genders for secondary school students
12.	Bastani et al. (2025)	Turkey	Field Experiment	GPT-4 (Generative AI)	Mathematics learning performance	Access to GPT-4 improved assignment scores, but without appropriate pedagogical design, it may be detrimental to long-term learning
13.	Putri et al. (2025)	Indonesia	Mixed Methods, Quasi-Experimental	AI tools	Mathematical critical thinking ability	Guided Inquiry model assisted by AI effectively improved students' mathematical critical thinking ability beyond the expository class
14.	Arifin et al. (2025)	Indonesia	R&D	AI-based LMS	Self-Regulated Learning (SRL) & perceived AI usefulness	AI-based LMS with personalized recommendation features and automatic feedback was perceived as highly helpful in addressing students' SRL problems
15.	Hao et al. (2024)	China	Quasi-Experimental	AI Precision Teaching	Science achievement & Self-Directed Learning	AI-supported precision teaching improved mathematics and chemistry achievement and stimulated senior high school students' self-directed learning

A systematic review of 15 studies from eight countries produced findings that consistently demonstrate the positive contribution of AI to the self-regulated learning and logical-mathematical thinking ability of senior high school students. However, this consistency cannot be interpreted simplistically as evidence that AI is always effective under all circumstances. The effectiveness of AI depends heavily on the type of technology employed, the pedagogical design that frames its use, as well as the characteristics of students and the context of implementation. Accordingly, the following discussion is structured as a thematic synthesis that aims to explain why, how, and under what conditions AI contributes to or potentially hinders mathematics learning at the senior high school level.

The Contribution of AI to Students' Self-Regulated Learning and Logical-Mathematical Thinking Ability

Findings across studies consistently indicate that AI contributes positively to senior high school students' self-regulated learning through mechanisms of adaptivity, personalization, and responsive feedback. Within Zimmerman (2000) Self-Regulated Learning framework, self-regulation develops optimally when students receive feedback that is specific, timely, and relevant and this is precisely what AI technology provides structurally. Mehmood et al. (2025) demonstrated this empirically ($p < 0.05$), while Adilah et al. (2025) and Arifin et al. (2025) reinforced this finding within the Indonesian context. The motivational dimension also plays a role, Ardiansyah & Wulandari (2026) found that AI personal tutors increased students' motivation to learn mathematics, while Hao et al. (2024) showed that AI Precision Teaching stimulated more autonomous self-directed learning. From an instrumentation perspective, Alatoai & Alshahri (2025) produced the AI-SSRSML instrument, which is valid, reliable, and applicable across genders, thereby addressing a gap not previously available in earlier reviews such as Zawacki-richter et al. (2019) and Holmes et al. (2019).

Regarding logical-mathematical thinking ability, the findings of this review can be understood through Piaget's cognitive constructivism: AI creates productive cognitive conflict through adaptive problem presentation, which serves as the primary driver of logical reasoning development. Assagaf & Subekti (2025) confirmed this positive relationship correlationally, while Elfani et al. (2025) reinforced it causally through experimental design. Chau et al. (2025) demonstrated that AI chatbots with adaptive feedback enhanced problem-solving by adjusting to students' zone of proximal development, thereby operationalizing Vygotsky's scaffolding within a technological context. Tashtoush et al. (2025) added a dimension that had previously been overlooked: AI not only improves mathematical critical thinking ability but simultaneously cultivates students' positive attitudes toward mathematics an affective dimension absent from earlier reviews such as Luckin et al. (2016).

Most Frequently Used AI Types, Their Characteristics, and Effective Implementation Designs

Among the 15 studies reviewed, three categories of AI technology were identified: (1) generative AI based on large language models such as ChatGPT and GPT-4; (2) Intelligent Tutoring Systems and adaptive AI-based LMS; and (3) rule-based and deep learning chatbots. Generative AI dominated the most recent studies (2024–2026), reflecting a shift in research interest from rule-based systems toward more flexible language models. Ng et al. (2024) demonstrated that ChatGPT-based chatbots produced more significant gains in self-regulated learning compared to rule-based AI, indicating that interactional flexibility is an important variable in AI effectiveness a cross-generational technology comparison not conducted by Zawacki-richter et al. (2019).

However, the type of technology alone does not determine AI's effectiveness, as implementation design has proven far more decisive. Putri et al. (2025) demonstrated that the Guided Inquiry model assisted by AI produced greater improvements in mathematical critical thinking than the expository approach. Mardhatillah et al. (2025) found that personalization features increased student engagement as a mediator between AI features and cognitive ability. Synthetically, effective implementation designs incorporate three key elements: personalization based on learning profiles, adaptive and timely feedback, and integration within a goal-oriented

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pedagogical model consistent with Luckin et al. (2016) assertion that AI's potential is only realized within a pedagogical ecosystem that is systematically and purposefully designed.

Moderating Factors, Risks of AI Use Without Pedagogical Design, and the Novelty of This Review

The effectiveness of AI does not stand independently but is influenced by several contextual factors. First, students' digital readiness. Wardhani et al. (2025) indicated that students in the Society 5.0 era generally support the use of AI, yet uneven readiness among students may create disparities in the benefits obtained. Second, gender as a factor. Alatoai & Alshahri (2025) found that the AI-assisted self-regulated learning instrument they developed applied equally to male and female students, although this finding still needs to be tested in more diverse contexts. Third, cultural and geographical context. The diversity of findings from eight countries in this review indicates that the benefits of AI may vary depending on cultural norms and the availability of technological infrastructure in each region. Fourth, the quality of research design. Studies with controlled experimental designs yield stronger evidence than correlational studies, so conclusions about AI's effectiveness need to be calibrated according to the methodological rigor of the underlying studies.

In terms of risks, the most critical finding originates from Bastani et al. (2025), that study demonstrated access to GPT-4 without structured pedagogical support can indeed improve short-term assignment scores, but may be detrimental to students' long-term understanding because students tend to rely on AI-generated answers without genuinely constructing their own conceptual understanding. Bastani et al. (2025) represents the only study in this review that explicitly identifies the conditional negative impact of AI use. This condition reflects a general tendency in educational technology research, where studies with positive findings are more frequently published than those reporting negative outcomes. In alignment with this, Ulfah (2024) cautioned that AI risks promoting shallow learning when not accompanied by meaningful instructional design.

Based on the overall findings above, this review makes contributions that can be identified specifically against the gaps in the existing literature. Compared to Zawacki-richter et al. (2019) systematic review, which covered only higher education and AI technologies predating the generative era, this systematic review specifically targets the senior high school level while simultaneously considering both generative and conventional AI use. Compared to Holmes et al. (2019) review, which discussed AI in education broadly without focusing on specific variables, this review integrates its focus on two primary variables: self-regulated learning and logical-mathematical thinking ability of senior high school students. Compared to Kulik & Fletcher (2016) review, which emphasized cognitive effect sizes more heavily, this review explicitly addresses the affective dimension as well as the conditional risks of AI use in mathematics learning.

Theoretical, Practical, and Methodological Implications

Theoretically, this review reinforces the relevance of Zimmerman (2000), Self-Regulated Learning framework and Piaget's constructivism while simultaneously extending them to the context of generative AI a development not anticipated by those frameworks. The capacity of generative AI to interact in a naturalistic manner challenges the assumption that cognitive scaffolding can only be provided by humans or rule-based systems. The affective dimension identified by Tashtoush et al. (2025) also urges theories of mathematics learning to integrate attitudinal components more systematically, moving beyond the predominant cognitive focus in the current literature. Practically, three primary recommendations are generated for mathematics educators and curriculum designers at the senior high school level. First, the integration of AI must be accompanied by explicit pedagogical design clear learning objectives, structured scaffolding, and metacognitive reflection so that its benefits extend beyond short-term score improvement. Second, the selection of AI types should align with instructional goals: generative AI for conceptual exploration and adaptive ITS for structured practice. Third, teachers need to develop their digital pedagogical competence so that they are capable of designing and critically evaluating AI implementation. Methodologically, future research needs to employ longitudinal designs to capture the dynamics of self-regulated learning and logical-mathematical thinking ability over time, as well as apply more systematic moderator analysis beyond the post-test score measurement that dominates the studies in this corpus.

Limitations of the Study

Although this study contributes to the understanding of the influence of Artificial Intelligence (AI) on the self-regulated learning and logical-mathematical thinking ability of senior high school students, several limitations must be considered when interpreting the findings. First, a corpus of 15 articles is sufficient for thematic synthesis but too small for a formal meta-analysis, meaning the findings are thematic-narrative in nature and require confirmation with a larger corpus. Second, the use of Google Scholar as a single source risks missing articles indexed exclusively in Scopus, Web of Science, or ERIC. Third, the time frame of 2024–2026 limits longitudinal comparison with earlier studies. Fourth, the heterogeneity of research designs experimental, quasi-experimental, correlational, instrument development makes direct comparison of effect sizes difficult. Fifth, publication bias toward positive findings is a structural challenge in educational technology systematic literature reviews, meaning this corpus likely over-represents the positive impacts of AI. These limitations should serve as critical notes in interpreting the findings and as an important agenda for future research

Conclusion

Systematic review of 15 empirical studies drawn from eight countries confirms that the integration of Artificial Intelligence in mathematics learning consistently exerts a positive influence on the self-regulated learning and logical-mathematical thinking skills of senior secondary students. Self-regulated learning develops through mechanisms of adaptive feedback, content personalization, and metacognitive support, while logical-mathematical thinking improves when AI functions as a cognitive partner that generates appropriately challenging tasks within each student's zone of proximal development. Nevertheless, these positive effects are conditional in nature: the effectiveness of AI is substantially determined by the quality of the pedagogical design that frames its use, as deployment without a structured instructional framework risks undermining the depth of long-term learning.

From a practical standpoint, senior secondary mathematics teachers must position AI as an instrument of formative feedback and a facilitator of reasoning, rather than as a source of immediate answers. This can be realized through the deliberate design of activities that encourage students to reflect on their own thinking processes, the gradual application of AI-based scaffolding, and the establishment of clear protocols that minimize student dependence on direct AI-generated solutions. This study contributes to the field by simultaneously examining two central variables at the senior secondary level and by comparing the effectiveness of generative AI with that of conventional adaptive AI systems within a unified corpus. Its limitations include reliance on a single database, heterogeneity in research design

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across studies, and a narrow publication window that may have excluded studies relevant to the period prior to 2024. Future research is therefore encouraged to broaden the scope of databases consulted, extend the temporal range of the review, and experimentally examine the role of pedagogical design as a moderating variable in AI effectiveness.

Conflict of Interest

The authors declare that there are no conflicts of interest

Auhor Contributions

H.P. conceptualized the research idea, developed the research design, conducted the literature review, and drafted the initial manuscript. N., as the supervising lecturer, contributed to the development of concepts and theoretical foundations, methodological validation, discussion of findings, as well as providing supervision and critical revision of the manuscript. All authors confirm that the final version of this paper has been read and approved. The total percentage of contribution to the conceptualization, writing, and revision of this paper is as follows: H.P.: 70% and N.: 30%.

Data Availability Statement

The authors declare that data sharing is not applicable, as no new data were created or analyzed in this study

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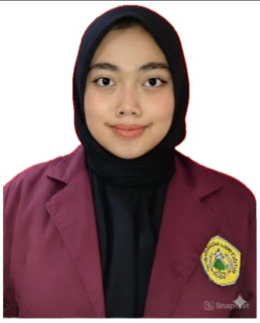	**Handayani Putri** is an undergraduate student in the Mathematics Education Study Program, Faculty of Teacher Training and Education, Universitas Sultan Ageng Tirtayasa, Indonesia. Her research interests include mathematics learning, self-regulated learning, mathematical logical thinking skills, and the use of Artificial Intelligence in education. ✉ 2225230028@untirta.ac.id
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