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Enhancing or Hindering Mathematical Creativity? A Systematic Literature Review of Generative AI in Secondary Mathematics Education

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ABSTRACT

Abstract: *The development of Generative AI (Generative AI) in mathematics education has yielded mixed findings regarding its impact on mathematical creativity. This study aims to analyze the role of Generative AI in enhancing or hindering mathematical creativity and to identify the factors that determine its impact. The study employed a Systematic Literature Review following the PRISMA guidelines, analyzing 27 empirical articles obtained through Google Scholar, Elicit and Scopus that met the inclusion criteria: published between 2023 and 2026 and discussing the use of Generative AI in secondary school mathematics education. The synthesis results reveal three main findings: Generative AI supports the development of fluency, flexibility, originality, and creative problem-solving; it has the potential to hinder creativity through cognitive dependence and a decline in originality; and its effectiveness is influenced by instructional design, the teacher's role, prompt quality, AI literacy, and students' metacognition. These findings provide a foundation for the more effective implementation of Generative AI to foster mathematical creativity.*

Kata Kunci:
AI Generatif
Kreativitas Matematis
Tinjauan Pustaka Sistematis
Pembelajaran yang Didukung AI

Abstrak: Perkembangan *Generative AI* (Generative AI) dalam pembelajaran matematika menimbulkan perbedaan temuan mengenai pengaruhnya terhadap kreativitas matematis. Penelitian ini bertujuan menganalisis peran Generative AI dalam meningkatkan maupun menghambat kreativitas matematis serta mengidentifikasi faktor yang menentukan dampaknya. Penelitian menggunakan metode *Systematic Literature Review* dengan pedoman PRISMA terhadap 27 artikel empiris yang diperoleh melalui Google Scholar, Elicit dan Scopus serta memenuhi kriteria inklusi yaitu dipublikasikan pada periode 2023–2026 serta membahas pemanfaatan Generative AI dalam pembelajaran matematika sekolah menengah. Hasil sintesis menunjukkan tiga temuan utama: Generative AI mendukung pengembangan *fluency*, *flexibility*, *originality*, dan penyelesaian masalah kreatif; berpotensi menghambat kreativitas melalui ketergantungan kognitif dan penurunan orisinalitas; serta efektivitasnya dipengaruhi oleh desain pembelajaran, peran guru, kualitas *prompt*, literasi AI, dan metakognisi peserta didik. Temuan ini menjadi dasar bagi implementasi Generative AI yang lebih efektif untuk mengembangkan kreativitas matematis.

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A. INTRODUCTION

Mathematical creativity refers to students' capacity to generate or develop novel, diverse, and valuable mathematical ideas, strategies, solutions, and problems within mathematical contexts (Sipahi & Bahar, 2025). In mathematics education research, this ability is commonly examined through fluency, flexibility, and originality, although the operational indicators and task types vary across studies (Suherman & Vidakovich, 2022). Thus, mathematical creativity reflects how students explore, modify, and evaluate ideas when dealing

with mathematical problems. In secondary education, this ability deserves particular attention because students increasingly encounter problems that allow more than one solution strategy.

In response to this need, Artificial Intelligence (AI) has been applied in mathematics education through intelligent tutoring systems, profiling and prediction, and adaptive systems (Hwang & Tu, 2021). The emergence of Generative AI expands these possibilities through language-based interactions that can dynamically generate responses and learning materials. A systematic review of 30 empirical K–12 studies found that much of the existing Generative AI research focuses on high-school and preservice-teacher contexts (Alfarwan, 2025). However, the availability of technology does not automatically enhance mathematical creativity, as its effect still depends on how students use it and how teachers integrate it into learning activities.

Several studies in secondary education suggest that Generative AI can support idea exploration when students remain active agents in the learning process. In a study involving ten tenth-graders, ChatGPT supported assumption generation and reduced the initial workload while students worked on mathematical modelling tasks (Bulut & Ferri, 2026). A large-scale field experiment involving nearly 1,000 high-school mathematics students also found that GPT Tutor improved practice performance by 127% through support designed to safeguard students' learning processes (Bastani et al., 2025). Similarly, in a high-school geometry project, students received Gemini feedback on their designs, revised their work, and reflected on the changes; teacher evaluations indicated positive contributions of AI to creativity and critical thinking (Baez et al., 2025).

However, Generative AI can become a constraint when its outputs replace students' own evaluation and reasoning processes. In the study of ten tenth-graders, most interactions with ChatGPT relied on zero-shot prompting, while answer validation and interpretation were largely absent (Bulut & Ferri, 2026). The field experiment involving nearly 1,000 high-school students showed that GPT Base increased practice performance by 48% while AI access was available (Bastani et al., 2025). Yet, when AI access was removed, the students in this group obtained test scores that were 17% lower than those of the control group, whereas the safeguards in GPT Tutor substantially mitigated this negative effect (Bastani et al., 2025). Consistent with these findings, a review of ChatGPT in mathematics education identified inaccurate outputs, ethical concerns, and over-reliance as important challenges for its educational use (Pepin et al., 2025).

These contrasting findings indicate that the impact of Generative AI is determined not only by access to the technology but, more importantly, by the design of the learning interaction surrounding it. The comparison between GPT Base and GPT Tutor suggests that guardrails designed to protect learning processes can reduce the risks of unrestricted AI use (Bastani et al., 2025). In the high-school geometry project, AI feedback was accompanied by revision and reflection activities, allowing students to remain involved in developing their work (Baez et al., 2025). In contrast, the limited prompting strategies and lack of verification among the ten tenth-graders constrained their engagement in deeper reasoning processes (Bulut & Ferri, 2026). Therefore, task design, prompt quality, scaffolding, critical evaluation, and teacher guidance are essential conditions for ensuring that Generative AI supports rather than replaces students' mathematical creativity.

Although research on Generative AI continues to grow, evidence that specifically maps its impact on secondary students' mathematical creativity remains scattered. Alfarwan's (2025) systematic review included 30 empirical studies of Generative AI across diverse K–12 subjects and educational contexts. Meanwhile, Pepin et al. (2025) mapped the benefits, challenges, and implications of ChatGPT in mathematics education more broadly. Based on the scope of these reviews, mathematical creativity in secondary education has not yet become the focus of a dedicated synthesis. Therefore, the novelty of this study lies in systematically examining the conditions under which Generative AI enhances or hinders mathematical creativity in secondary mathematics education.

Based on this gap, this study aims to systematically analyse the role of Generative AI in enhancing or hindering students' mathematical creativity in secondary mathematics education. The review identifies forms of Generative AI use, implemented learning activities, reported effects, potential risks, and factors that determine the effectiveness of its use. The findings are expected to guide teachers and schools in designing Generative AI-supported learning that continues to promote idea exploration, independent reasoning, and students' active engagement in mathematics learning.

B. METHOD

This study employs a Systematic Literature Review (SLR) method with a qualitative descriptive approach to systematically identify, evaluate, and synthesize various empirical studies on the impact of Generative AI

(Generative AI) on mathematical creativity. The SLR method was chosen because it provides a comprehensive overview of research developments, patterns of findings, and research gaps through a structured, transparent, and replicable literature search process. This study aims to systematically examine the forms of Generative AI utilization, learning activities, its impact on mathematical creativity, potential risks, and factors influencing the effectiveness of its use in mathematics education. Research data were obtained from various academic databases and AI-based literature search platforms, namely Google Scholar, Elicit, and Scopus. The research stages are presented in Figure 1.

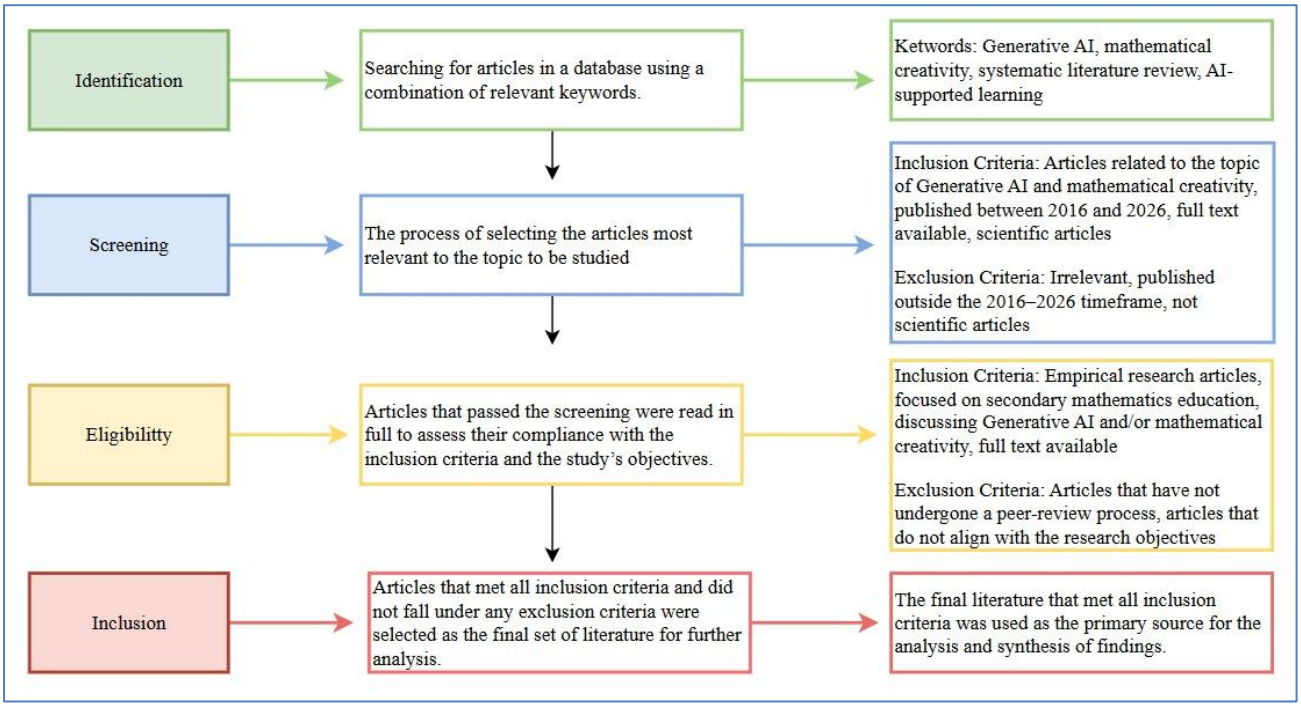

Figure 1. Research Procedure Chart

Based on figure 1, a systematic literature review was conducted using a combination of relevant keywords, such as Generative AI; Mathematical Creativity; Systematic Literature Review; AI-Supported Learning. Selected articles had to meet the following inclusion criteria: (1) they were empirical studies using quantitative, qualitative, or mixed-methods approaches; (2) they were published between 2016 and 2026; (3) discuss the use of AI in the context of mathematics education; (4) examine mathematical creativity either directly or indirectly; and (5) be available in full text and written in English. Meanwhile, articles were excluded from the analysis if they were literature reviews, editorials, opinion pieces, conference proceedings without full texts, books, undergraduate theses, master's theses, doctoral dissertations, duplicate articles, or publications not aligned with the research focus. All retrieved articles were then managed using reference management software to remove duplicate entries before proceeding to the next selection stage.

The literature selection procedure followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which include the identification, screening, eligibility, and inclusion stages (Page et al., 2021). During the identification stage, all articles obtained from various sources were collected, and duplicate articles were removed. Next, during the screening stage, articles were selected based on their titles and abstracts to ensure their relevance to the research focus. Articles that passed this stage were then thoroughly analyzed through a full-text review during the eligibility stage based on the established inclusion and exclusion criteria. Articles that met all criteria then proceeded to the inclusion stage and were analyzed using thematic analysis through a process of data extraction, grouping, and synthesis based on five main aspects: forms of Generative AI utilization, learning activities, its impact on mathematical creativity, potential risks of using Generative AI, and factors influencing the effectiveness of its use. To ensure the validity and reliability of the research results, the data extraction and coding processes were conducted systematically using a consistent review protocol, and each article was re-examined to ensure the accuracy of classification, consistency of interpretation, and accuracy of the synthesis of research findings.

C. RESULT AND DISCUSSION

1. Overview of the Synthesis Result

This review analyzes 27 unique sources that discuss the use of Generative AI in relation to creativity, mathematical creativity, creative problem-solving, mathematical problem-posing, mathematical reasoning, and factors influencing the quality of students' interactions with AI. Although the literature search covered publications from 2016 to 2026, only studies published between 2023 and 2026 met all the predefined inclusion and eligibility criteria and were therefore included in the final review. These articles draw on a variety of research designs, including experiments, quasi-experiments, case studies, mixed methods, development research, and exploratory studies. Most studies focus on middle school mathematics education, although several other sources have examined higher education or STEM contexts relevant to creative processes, such as problem-solving, task design, visualization, and modeling. The thematic analysis yielded three main themes. The first theme indicates that Generative AI can support mathematical creativity through idea expansion, alternative strategies, feedback, solution elaboration, and problem exploration. The second theme suggests that the use of AI can hinder creativity if students accept the system's output directly, reduce the evaluation process, or rely too heavily on AI-generated responses. The third theme indicates that the impact of AI is not automatic but is determined by activity design, the teacher's role, the quality of prompts, AI literacy, metacognition, and students' independent thinking.

Table 1. Review Analysis

Theme	Subtheme	Synthetic Findings	Frequency
Generative AI as a tool for mathematical creativity	Improving Divergent Mathematical Thinking	Generative AI helps improve fluency, flexibility, originality, and the ability to generate various alternatives for solving math problems.	8 Articles
	Mathematical exploration and creative problem solving	Generative AI supports problem formulation, modeling, visualization, automated feedback, reflection, and the refinement of problem-solving strategies.	7 Articles
Generative AI as a barrier to mathematical creativity	Cognitive dependence and a decline in independent thinking	Overreliance on AI leads to dependence on instant answers, passive learning, and a decline in independent thinking	3 Articles
	A decline in originality and diversity of ideas	AI responses, which tend to be structured and uniform, can limit the emergence of new strategies and the diversity of students' mathematical ideas.	2 Articles
Factors That Determine the Impact of Generative AI	Pedagogical factors	*Scaffolding, task design, prompt quality, AI integration, and the teacher's role determine the effectiveness of AI in mathematics education.*	4 Articles
	Student factors	AI literacy, metacognition, critical evaluation, early mathematical skills, and self-regulation determine the quality of students' interactions with AI.	3 Articles

The included studies examine the application of Generative AI in mathematics education using various research designs. The distribution of articles by year of publication is shown in Figure 2.

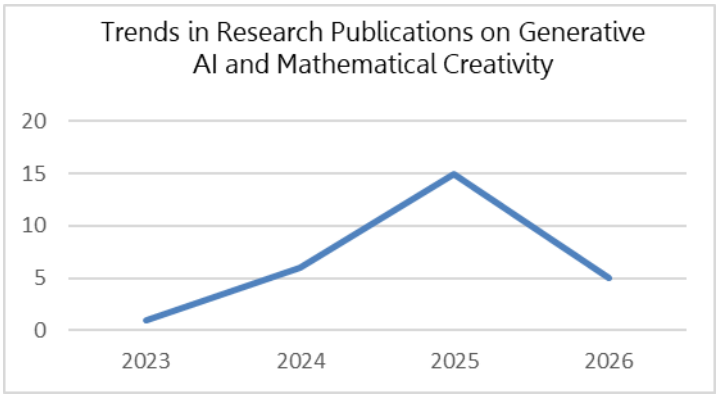

Figure 2. Trends in Research Publications

Based on Figure 2 publications on the use of Generative AI in mathematics education showed a fairly significant increase during the study period. This distribution indicates that the majority of the studies analyzed were published in the last two years 2025 and 2026 suggesting that the use of Generative AI in mathematics education is a rapidly evolving field of study that is gaining increasing attention in empirical research.

2. Generative AI as a Tool for Mathematical Creativity

a. Enhancing Divergent Mathematical Thinking

The most prominent finding in the positive study group indicates that Generative AI expands learners' opportunities to generate more than one idea or problem-solving strategy. In this context, AI is not merely used as a provider of final answers, but as a source of alternative procedures, examples, representations, and follow-up questions that learners can explore. Zein et al. (2024) found that using ChatGPT as a virtual tutor through probing-prompting activities can enhance students' creative abilities when prompts are used to explore and compare alternative answers. A similar pattern was found by Fauzi et al. (2025), who showed that students can use AI as a source of inspiration, guidance, and confirmation before formulating more than one relevant problem-solving strategy.

Evidence of increased creativity was also evident in a quasi-experimental study at the high school level. Salsabila & Maysarah (2025) reported that mathematics learning assisted by Gemini.AI resulted in a higher increase in creative thinking skills compared to learning without AI assistance. In that study, the experimental class achieved an average N-Gain of 61.65%, while the control class achieved an N-Gain of 50.42%. Consistent results were found by Antoro et al. (2025), who reported improvements in fluency, flexibility, and originality after students used an AI-based learning application that provided adaptive questions, interactive visualizations, automatic feedback, and open-ended challenges.

However, this improvement was not always consistent across all creativity indicators. Students were better able to formulate solution steps in a sequential, detailed, and coherent manner. Nevertheless, the findings of a study conducted by Istikomah et al. (2014) indicate that the development of flexibility and originality remains limited because some students have not yet been able to develop strategies that are truly different from AI response patterns. These findings suggest that Generative AI is better at helping students elaborate on existing ideas than at generating entirely new approaches.

This pattern aligns with the study by Setiaji et al. (2025) on discovery-learning-based physics instruction. Although the context is not directly mathematics education, the study shows that AI can support fluency, flexibility, and originality when students are engaged in exploration, proposing ideas, and formulating alternative solutions. Kim et al. (2025) also reported that an educational program based on design thinking and Generative AI enhances middle school students' creative problem-solving abilities through activities such as building personas, understanding user needs, and reconstructing problem situations. Thus, cross-context evidence suggests that AI supports divergent thinking when learning activities provide space for students to generate, compare, and modify multiple possible ideas

b. Mathematical Exploration and Creative Problem Solving

Generative AI also plays a role in expanding mathematical exploration through creative problem-solving, problem formulation, modeling, visualization, and solution refinement. Lee & So (2025) found that students who used ChatGPT to solve creative PISA problems did not simply ask for answers, but

developed strategies from their initial ideas, used a variety of prompts, and then leveraged the AI's responses to refine their solutions. These findings suggest that AI can enrich the problem-solving process when the system's output is used as material to expand ideas, rather than as an answer to be copied directly.

In the context of creating math problems, Walkington et al. (2025) demonstrated that female middle school students can use generative AI to create math word problems based on their own interests, experiences, characters, and contexts. Students utilized prompts to generate, refine, and develop problem contexts, including using chain prompting to refine initial ideas. AI accelerated the development of contextual variations and problem visualizations, while students remained active in selecting, adapting, and evaluating AI outputs in alignment with the mathematical objectives they established.

Exploratory activities are also evident in the use of Generative AI-based learning agents. Song et al. (2026) found that high school students viewed these agents as study buddies, facilitators, and problem-solving partners. Through "learning-by-teaching" activities, students explain their strategies and reasoning to the AI, then use the AI's follow-up questions or responses to refine their explanations, consider alternative solutions, and reflect on their thinking. This process demonstrates that interactions with AI can support the evaluation of strategies, particularly when students are asked to explain their mathematical reasoning.

In a high school geometry project, Baez et al. (2025) also demonstrated that Gemini and ChatGPT can be used to provide feedback on proofs, geometric solutions, and art designs based on translation, rotation, reflection, and dilation. Students then used this feedback to revise their designs and mathematical arguments. Meanwhile, Aliyah (2025) demonstrated that worksheets based on question-probing scaffolding that utilize Perplexity AI can enhance creative thinking skills in the context of relations and functions. This improvement arose because the progressive questions guided students to explore information, analyze problems, and formulate solutions independently.

More structured results were obtained by Umam et al. (2026) through the integration of the GASING pedagogy and ChatGPT-4o. In that study, students followed a "logic-first" approach: they explained their initial reasoning, received step-by-step guidance, explored alternative strategies, and verified their ideas using AI. AI adoption is positively associated with mathematical creativity, while mathematical creativity acts as a mediator between AI use and problem-solving ability. However, Bulut & Ferri (2026) found that many high school students still rely heavily on zero-shot prompting and rarely perform in-depth validation or interpretation of ChatGPT's outputs. These findings suggest that AI can facilitate initial ideation, but in-depth mathematical exploration still requires guidance so that students do not stop at the early stages of simplifying or mathematizing a problem.

3. Generative AI as a Barrier to Mathematical Creativity

a. Cognitive Dependence and a Decline in Independent Thinking

The negative findings do not indicate that Generative AI always reduces creativity. On the contrary, these findings show that risks arise when AI is used as a substitute for the thinking process. Toma & Pérez (2024) found that using ChatGPT for ten weeks did not overall reduce students' creativity. However, the results varied among participants: some experienced an increase, some remained the same, and others experienced a decrease. These findings confirm that the impact of AI on creativity is not uniform and depends heavily on individual usage patterns.

The risk of dependency is more evident when students accept AI responses without evaluation. Yoon et al. (2024) found that in mathematical proof activities, some students accepted AI-generated proofs without conducting in-depth mathematical verification. This situation reduces students' opportunities to assess the validity of arguments, trace the structure of proofs, and explore alternative strategies. In the context of mathematics learning, the immediate acceptance of AI outputs has the potential to limit the reasoning processes that are actually necessary for building mathematical creativity.

Habib et al. (2024) also demonstrated that Generative AI can enhance the fluency of idea generation, but excessive use can diminish creative confidence, divergent thinking, and originality. Similar risks were identified by Sun et al. (2024) in programming education. Although ChatGPT aided task completion, some students expressed concerns about reliance on AI and reduced cognitive engagement when AI was used unsupervised. These findings are relevant to mathematics education because both fields require the process of trying out strategies, identifying errors, evaluating steps, and building understanding independently.

b. A Decline in the Originality and Diversity of Mathematical Ideas

The second obstacle relates to the tendency for responses to become uniform. Meincke et al. (2025) found that ChatGPT can help generate ideas that appear creative, but the use of such systems has the potential to reduce the diversity of ideas in brainstorming activities. This finding is important because creativity is not only related to the number of ideas but also to the variety, novelty, and diversity of approaches generated.

In mathematics education, the risk of homogenization of responses can be observed when students use the same procedures, representations, or patterns of explanation as the AI's output. Fineldi et al. (2026) demonstrated that ChatGPT can help students break down the steps for solving geometry problems, but it has not consistently generated flexible and original strategies. Fauzi et al. (2025) also found that students with low mathematical ability tend to accept AI answers without significant modification. This situation limits their development of flexibility and originality compared to students who use AI as a reference.

Baklaga (2026) argues that AI plays a dual role in creativity. AI can aid in idea exploration and problem-solving, but overreliance on it can reduce human agency and limit creative expression. In mathematics education, these findings suggest that AI responses should be treated as discussion points rather than as the sole model to be followed. Students need to be given the opportunity to reject, modify, or compare AI responses with other strategies so that a diversity of ideas can continue to flourish

4. Factors That Determine the Impact of Generative Thinking on Mathematical Creativity

a. Pedagogical Factors

The synthesis results indicate that instructional design is the primary factor distinguishing productive AI use from substitutive AI use. AI more frequently supports creativity when learners are asked to formulate step-by-step prompts, compare several alternatives, explain mathematical reasoning, check the accuracy of responses, and revise solutions. Liu et al. (2026) demonstrated that ChatGPT supports fluency, flexibility, and originality when used as a co-creator in activities involving exploration, evaluation, and the development of alternative solutions. However, these benefits depend on students' ability to monitor and reflect on AI outputs.

The role of scaffolding also appears consistent across several studies. Huda et al. (2025) found that using ChatGPT as scaffolding in guided inquiry learning helps improve metacognitive skills and conceptual understanding of limits. However, the study also identified the potential for passive engagement and dependence on AI if the learning monitoring process is not properly managed. Aliyah (2025) provided supporting evidence at the junior high school level, showing that step by step questions in worksheets help students explore information and construct solutions, while Perplexity AI functions as part of learning support, not as a substitute for thinking activities.

The type of task also determines the extent of creativity that can emerge. Cahyono et al. (2025) demonstrate that open-ended, exploratory STEAM tasks that allow for more than one solution foster creativity through visualization, interdisciplinary integration, and idea development. Kim et al. (2025) show that AI-assisted design thinking enhances creative problem-solving because students do not immediately seek answers but instead build personas, understand the problem, and reconstruct user needs. In mathematics education, this pattern suggests that open-ended tasks, problem posing, modeling, and non-routine problems are better suited for using AI as a catalyst for exploration rather than as a tool for finding answers.

Teachers also play a crucial role in determining the quality of students' interactions with AI. Zein et al. (2024) found that students still require guidance and verification when using ChatGPT as a virtual tutor. Salsabila & Maysarah (2025) also show that increased creativity occurs within interactive AI-based learning sequences, not merely because students have access to Gemini.AI. Thus, teachers need to guide students to use AI in a dialogic manner by asking follow-up questions, requesting alternative solutions, comparing responses, and explaining the reasoning behind the chosen strategies.

b. Student Factors

Learner characteristics also determine whether AI is used as a source of enrichment or as a substitute for the thinking process. Fauzi et al. (2025) found that learners with higher mathematical ability tend to use AI as a source of inspiration and confirmation. They compare AI outputs with their existing strategies and then adjust them based on their conceptual understanding. Conversely, students with lower

initial ability are more likely to accept AI's answers directly without making modifications or conducting further verification.

These abilities are closely related to AI literacy. Abar et al. (2023) emphasize that AI literacy in mathematics education encompasses an understanding of AI's characteristics, the ability to identify problems suitable for AI assistance, critical evaluation of the system's outputs, and data literacy. Dahal (2025) also found a positive relationship between AI familiarity, mathematical creativity, and problem-solving ability. However, the study still highlights the risks of over-reliance, cognitive offloading, and accepting AI outputs without evaluation. Therefore, familiarity with using AI must be accompanied by the ability to test the accuracy and relevance of the generated responses.

Metacognition and self-regulation are other factors that determine the impact of AI. Liu et al. (2026) demonstrated that the increase in mathematical creativity was stronger when students monitored, evaluated, and reflected on ChatGPT's outputs. Huda et al. (2025) also identified metacognitive regulation as a crucial component of productive ChatGPT use. These findings are supported by Bulut & Ferri (2026), who show that the use of zero-shot prompting and a lack of validation limit the depth of students' engagement in mathematical modeling.

Furthermore, mathematical autonomy and critical evaluation skills influence how students approach AI responses. Yoon et al. (2024) demonstrate that the use of AI in mathematical proofs is more productive when students critically assess AI outputs, test arguments, and consider alternative proofs. Conversely, uncritical acceptance of AI-generated proofs limits reflection and the development of reasoning. Therefore, Generative AI should be understood not as a technology that inherently enhances or hinders mathematical creativity, but rather as a tool whose impact depends on instructional design and the quality of students' engagement in thinking.

Overall, this synthesis indicates that Generative AI can expand mathematical creativity through alternative strategies, feedback, problem exploration, problem formulation, and solution revision. However, these benefits only emerge optimally when AI is used as a thinking partner that needs to be questioned, compared, verified, and developed. When AI is used as a source of instant answers, the risks of cognitive dependence, homogenization of responses, and a decline in originality become greater.

D. CONCLUSIONS AND RECOMMENDATIONS

This systematic literature review shows that Generative AI can act as both a facilitator and an inhibitor of mathematical creativity in secondary mathematics education. Generative AI has the potential to enhance fluency, flexibility, originality, and elaboration through alternative strategies, feedback, problem exploration, problem formulation, visualization, and solution revision. However, these benefits do not arise automatically. When AI is used as a source of instant answers without evaluation or modification, students risk developing cognitive dependence, reduced independent thinking, and the homogenization of mathematical ideas. Thus, the impact of Generative AI on mathematical creativity is largely determined by instructional design, the teacher's role, the quality of prompts, AI literacy, metacognition, and students' ability to evaluate AI outputs.

The limitations of this study lie in the variation in context, research design, student grade levels, AI platforms, and creativity indicators used in the reviewed articles, meaning that comparisons of results across studies are not yet fully consistent. Future research needs to conduct longitudinal studies to examine the influence of Generative AI on fluency, flexibility, and originality among high school students, including when AI assistance is not available. Additionally, it is important to develop and test AI-assisted learning models that explicitly train students in prompt literacy, critical evaluation, metacognitive regulation, and mathematical autonomy so that AI truly functions as a thinking partner rather than a substitute for students' reasoning processes.

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