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Dialogic AI in the mathematics classroom: Exploring generative AI as a thinking partner for secondary education student

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ABSTRACT

This study aims to analyze the implementation of generative artificial intelligence (AI) as a dialogic thinking partner of secondary student in mathematics learning. The study employed a qualitative approach with a case study design and was conducted in May 2026. The research participants consisted of a mathematics teacher and 25 Phase F students who actively utilized generative AI during the learning process. Data were collected through classroom observations, semi-structured interviews, and documentation, including students' work, screenshots of interactions with AI, and instructional materials. The data were analyzed interactively through data condensation, data display, and conclusion drawing and verification, while the trustworthiness of the findings was established through source and method triangulation. The findings indicate that dialogic interactions between students and generative AI were formed through an iterative cycle of initial questioning, clarification, follow-up questioning, and verification, through which generative AI functioned as a dialogic thinking partner that supports students' understanding of mathematical concepts and expands their problem-solving strategies. Interaction with AI also encourages students to compare, verify, evaluate, and justify mathematical solutions, thereby supporting the development of critical thinking. However, the quality of AI utilization is strongly influenced by students' AI literacy, particularly their ability to formulate effective prompts and critically evaluate AI-generated outputs. The implementation of AI also transforms the teacher's role into that of a facilitator and guide who designs tasks requiring students to explain and verify AI-assisted solutions so that the use of technology supports, rather than replaces, students' own mathematical reasoning.

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INTRODUCTION

The rapid development of digital technology in recent years has brought fundamental changes to the global educational landscape, particularly through the emergence of Generative Artificial Intelligence (Generative AI). In the context of modern education, Generative AI is no longer viewed merely as a technical aid or an automated information retrieval tool; rather, it has transformed into an interactive entity with the potential to facilitate critical thinking processes and autonomous knowledge construction (Qawaqneh et

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al., 2023). This paradigm shift requires the field of education to adapt instructional strategies capable of utilizing advanced technologies wisely and systematically (Creed et al., 2022). Consequently, exploring the integration of Generative AI into secondary school learning environments becomes paramount to addressing the challenges of the digital age without compromising students' cognitive depth.

In secondary education, mathematics is frequently regarded as one of the most challenging subjects because it demands strong conceptual understanding, logical reasoning, and problem-solving flexibility. Particularly within Phase F of the Merdeka Curriculum (11th and 12th grades), mathematical topics such as functions, matrices, calculus, and probability require a high level of abstract thinking and complex procedural fluency (Saputra et al., 2025). However, limited time allotment during face-to-face classroom instruction often impedes teachers from providing individualized cognitive scaffolding aligned with each student's learning pace (Li et al., 2024). This situation often leads to cognitive blockages and difficulty among students in independently articulating mathematical problem-solving steps. The lack of opportunity to provide individual cognitive scaffolding impedes students from independently articulating their thought processes as they engage in mathematical problem solving.

As a solution to the limitations of conventional classroom interaction, implementing Generative AI as a dialogic thinking partner offers an efficient and realistic pedagogical approach to mathematics education. From the perspective of the Unified Theory of Acceptance and Use of Technology 2 (UTAUT 2) framework (Venkatesh et al., 2012), this function aligns closely with the constructs of *performance expectancy* and *facilitating conditions*, as students utilize the technology to enhance their cognitive learning performance while receiving continuous, on-demand instructional scaffolding. Serving as a thinking partner, Generative AI is not employed to produce instant answers or automatically complete assignments; instead, it facilitates interactive dialogue by asking follow-up questions, offering step-by-step hints, and providing alternative explanations (Liu et al., 2025). Through this dialogic interaction pattern, students are prompted to clarify their understanding, test logical reasoning, and reflectively identify errors in their thinking (Siswanto, 2025). This approach enables deeper mathematical exploration, where technology acts as a supportive cognitive scaffold that enhances, rather than replaces, students' cognitive engagement.

Nevertheless, the efficacy of utilizing Generative AI as a thinking partner is substantially determined by students' AI literacy and critical readiness when interacting with the technology. Without appropriate pedagogical guidance, integrating Generative AI risks inducing passive reliance, where students simply copy AI-generated procedures without comprehending the underlying mathematical principles (Adeoye et al., 2024). Furthermore, the potential for inaccuracies or hallucinations in AI outputs necessitates that students possess the skills to verify, evaluate, and critique information provided by the technology (Rochmat et al., 2025). Therefore, designing instructional activities that intentionally incorporate mathematical verification principles and academic ethics is essential to ensure that AI usage enhances students' critical thinking and learning autonomy.

SMA Muhammadiyah Mlati, as a faith-based secondary education institution, is committed to continuously adopting modern learning innovations aligned with student character development and academic ethics. Preliminary observations at SMA Muhammadiyah Mlati revealed that several students had independently begun using Generative AI tools to comprehend complex mathematical concepts. However, utilization patterns varied widely ranging from merely seeking final answers to engaging in interactive discussions and were not yet fully structured within teacher-guided learning scenarios (Kim, 2024). This dynamic highlights the need for a clear pedagogical framework to ensure that the

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integration of Generative AI at SMA Muhammadiyah Mlati operates optimally, ethically, and with a primary focus on strengthening conceptual understanding.

Given this context and urgency, an exploratory study investigating the implementation of Generative AI as a thinking partner of secondary students. This study focuses on revealing how dialogic interactions between students and generative AI are formed and how, through these interactions, AI functions as a thinking partner in understanding mathematical concepts; how AI supports problem-solving exploration and critical thinking; and how AI literacy levels and teacher roles transform classroom dynamics. The findings are expected to provide a comprehensive empirical overview of AI-assisted mathematics instruction models, serving as a practical reference for educators and policy makers seeking to integrate artificial intelligence technologies wisely, critically, and effectively in secondary education.

LITERATURE REVIEW

1. Generative AI

The integration of Generative Artificial Intelligence (GenAI) into the educational realm marks a significant paradigm shift in how learning materials are produced, customized, and delivered to students. Unlike conventional artificial intelligence systems that focus primarily on pattern recognition or static data classification, GenAI possesses advanced natural language processing capabilities capable of generating text, solving complex problems, and producing programming code responsively and adaptively (Wibowo & Siswanto, 2026). The accessibility of this technology enables the rapid synthesis of information, the modeling of personalized explanations tailored to students' comprehension levels, and the provision of immediate feedback without temporal or spatial constraints (Atit et al., 2022). This rapid development of GenAI is revolutionizing the learning environment from a traditional material-centered model into a highly interactive and individualized educational ecosystem.

Despite presenting transformative pedagogical potential, the implementation of GenAI in the educational landscape triggers critical challenges concerning information validity, cognitive bias, and data privacy. The ability of Large Language Models (LLMs) to produce answers that appear convincing yet are factually incorrect, a phenomenon known as hallucination demands a high degree of vigilance from educators and students alike (Cooper et al., 2024). Over-reliance on instructional automation also risks eroding independent critical thinking skills if it is not balanced with the design of appropriate learning tasks (Azmi & Kurniawan, 2025). Therefore, frameworks for integrating GenAI into education must strike a balance between technological flexibility and rigorous pedagogical oversight to ensure that technological engagement genuinely enriches the learning experience (UNESCO, 2023).

2. AI as a Thinking Partner

Before the emergence of Generative AI, educators and researchers relied on various pedagogical and technological alternatives to serve as cognitive "thinking partners" in mathematics classrooms. Traditionally, this dialogic role was fulfilled through human-centered scaffolding, such as teacher-led Socratic questioning, peer tutoring, and collaborative small-group discussions (Li et al., 2024). In the digital realm, early computer-based alternatives included Intelligent Tutoring Systems (ITS), Computer Algebra Systems (CAS), and dynamic geometry software such as GeoGebra, which provided rule-based hints, automated feedback, and visual representations (Wibowo & Siswanto, 2026). However, while human peers and teachers are constrained by classroom time and availability, traditional software tools often lacked natural language flexibility and were restricted to pre-programmed decision trees. Building upon these foundations, the role of artificial intelligence

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in education has evolved from a mere passive answering engine into a dynamic thinking partner within the cognitive process.

The role of artificial intelligence in education has evolved from a mere passive answering engine into a dynamic thinking partner within the cognitive process. The concept of GenAI as a thinking partner positions AI as a dialogic facilitator that encourages students to formulate questions, test hypotheses, and evaluate their own arguments through Socratic-based interactions (Walkington et al., 2024). In this dynamic, AI does not directly provide final solutions, but rather triggers students' metacognition through reflection, the provision of alternative perspectives, and structured instructional scaffolding (Pacheco et al., 2021). This collaborative interaction pattern creates a high-level learning environment where understanding is constructed iteratively through active dialogue between human and machine (Astuti et al., 2025).

Furthermore, implementing the thinking partner model has been shown to extend students' Zone of Proximal Development (ZPD) by providing customized cognitive support in real time. Through pedagogically designed prompt engineering, GenAI can challenge students' assumptions, help deconstruct complex problems into smaller components, and train logical idea articulation (Falloon, 2024). This approach reinforces self-regulated learning because students are driven to control the direction of their own intellectual exploration rather than passively receiving knowledge (Zimmerman, 2002). Consequently, this interactive relationship with AI transforms the learning process from rote memorization into deep exploration and knowledge construction.

3. Mathematics Learning

In the field of mathematics education, generative artificial intelligence opens up new opportunities to overcome cognitive abstraction barriers and math anxiety often experienced by learners. Mathematics demands strong procedural and conceptual reasoning, where a lack of understanding of a single foundational concept can hinder the mastery of subsequent topics (Batubara et al., 2026). GenAI functions as an adaptive private tutor by delivering step-by-step problem-solving explanations, presenting abstract concept visualizations through contextual descriptions, and providing varied practice exercises tailored to the learning pace of each individual (Ilhan & Akin, 2022). This personalization helps students identify mathematical misconceptions early before they become persistent learning obstacles.

Furthermore, the application of GenAI in mathematics shifts the instructional focus from mechanical computation to higher-order mathematical reasoning and problem-solving skills. When AI handles routine computational burdens, students gain greater cognitive capacity to explore problem-solving strategies, compare the efficiency of various methods, and apply mathematical concepts to real-world scenarios (National Council of Teachers of Mathematics [NCTM], 2000). Interacting with an AI-based thinking partner allows students to articulate and verify the logical steps of their mathematical reasoning while acquiring a holistic understanding of inter-topic connections (Jablonski & Ludwig, 2022). This transformation fosters the achievement of robust mathematical literacy aligned with 21st-century problem-solving demands.

4. AI Literacy

As the adoption of intelligent technologies becomes increasingly pervasive throughout society, AI literacy has emerged as an essential competency for both educators and students. AI literacy encompasses not only basic technical knowledge regarding how algorithms and machine learning models operate, but also the critical and ethical capability to evaluate, utilize, and interact with AI systems (Gill et al., 2024). Without adequate AI literacy, individuals

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risk uncritically accepting AI outputs without proper verification, or conversely, rejecting the potential benefits of this technology due to unfounded anxieties (Siswanto, 2025). Consequently, integrating AI literacy into educational curricula is a fundamental prerequisite for preparing a capable generation in the digital era.

Comprehensive AI literacy development spans three main dimensions: cognitive understanding, ethical evaluation, and practical proficiency in prompt engineering. Cognitive understanding enables individuals to recognize the inherent limitations and biases embedded within AI training data, whereas ethical evaluation equips them with awareness regarding copyright, privacy, and academic integrity (Sharma et al., 2023). On the other hand, practical competence in interacting with AI ensures that users can effectively direct artificial intelligence systems to support their cognitive goals without compromising intellectual honesty (Barbieri et al., 2020). Ultimately, AI literacy serves as the vital foundation ensuring that the use of GenAI as a thinking partner remains safe, responsible, and effective.

METHODS

This study employed a qualitative research approach with a case study design to explore in depth the implementation of generative artificial intelligence (GenAI) as a dialogic thinking partner in Phase F Mathematics learning at SMA Muhammadiyah Mlati (Creswell & Creswell, 2018; Yin, 2018). The research participants comprised a mathematics teacher and 25 Phase F students (grade XI, academic year 2025/2026) who were purposely selected because they were actively engaged in utilizing GenAI during learning activities. In reporting the results, the teacher is coded as T and the students as S1–S25. Data collection was conducted through three primary techniques: classroom observations, semi-structured interviews, and documentation. Classroom observations focused on observing the dynamics of student interaction with GenAI in understanding mathematical concepts, exploring problem-solving strategies, verifying AI-generated solutions, and developing mathematical critical thinking. Semi-structured interviews were conducted using an initial guide based on five analytical dimensions, serving as a flexible framework (Patton, 2015).

According to Patton (2015), a semi-structured interview guide built around predetermined topical dimensions ensures systematic coverage of core inquiry areas across participants while preserving the interviewer's freedom to adapt question wording, sequence, and follow-up probes in response to emergent insights. In this study, utilizing the five analytical dimensions provided clear conceptual boundaries to maintain focus on dialogic AI interactions without restricting participants to rigid, closed-ended responses, thereby allowing authentic student and teacher experiences to surface organically during the interview. Interviews with students explored prompt formulation, evaluation/verification of AI-generated answers, technical obstacles, the level of understanding regarding AI limitations, and awareness of academic ethics. Meanwhile, interviews with the teacher examined the rationale for GenAI integration, dialogic pedagogical strategies, shifts in student thinking patterns, AI literacy challenges, and the transformation of the educator's role. This data collection was reinforced by documentation consisting of students' mathematical work, screenshots of interactions with AI, instructional materials, and other relevant pedagogical records (Marshall & Rossman, 2016).

The interview guide was prepared in advance and developed based on the five analytical dimensions of this study. For each dimension, the guide included initial guiding questions for both students and teachers (Table 1), followed by probing questions such as, “Can you provide an example?”, “What did you do next?”, and “Why did you decide to do that?” These questions were used flexibly, depending on the participants’ responses. The

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student interviews were conducted on May 11, 2026, and lasted approximately 40 minutes, while the teacher interviews lasted approximately 30 minutes. All interviews were conducted in Indonesian, audio-recorded with the participants' consent, transcribed verbatim, and translated into English for reporting purposes.

Table 1. Initial Guiding Questions of the Semi-Structured Interviews

Informant	Dimension	Initial guiding question
Students	Prompt formulation	How do you formulate prompts when asking generative AI for help with mathematical problems?
Students	Evaluation and verification of AI-generated answers	How do you evaluate and verify the accuracy of mathematical answers and solution steps generated by AI?
Students	Technical obstacles	What technical difficulties do you encounter when accessing and using generative AI for mathematics learning?
Students	Understanding of AI limitations	Have you ever encountered incorrect or inconsistent AI-generated responses? How did you recognize and address them?
Students	Awareness of academic ethics	How do you ensure that using AI supports your own understanding rather than simply copying AI-generated answers?
Teacher	Rationale for GenAI integration	Why do you integrate generative AI into mathematics learning, and what learning benefits do you expect it to provide?
Teacher	Dialogic pedagogical strategies	How do you encourage students to engage in meaningful dialogue with AI through follow-up questions, clarification requests, and purposeful prompts?
Teacher	Shifts in students' thinking patterns	What changes have you observed in students' mathematical thinking and problem-solving strategies when using generative AI?
Teacher	AI literacy challenges	What challenges do students face in understanding AI limitations, formulating effective prompts, and evaluating AI-generated responses?
Teacher	Transformation of the teacher's role	How has the integration of generative AI changed your role in guiding, monitoring, and evaluating students' mathematical learning?

Data analysis was conducted interactively and continuously following the model of Miles et al. (2014), which encompasses three main stages: data condensation, data display, and conclusion drawing and verification. To ensure the trustworthiness and credibility of the findings, this study applied triangulation of data sources and data collection techniques by comparing and cross-checking evidence obtained from observations, interviews, and documentation (Denzin, 2012; Lincoln & Guba, 1985). The comprehensive analytical process focused on five major dimensions: (1) the role of GenAI as a dialogic thinking partner for conceptual understanding; (2) the contribution of GenAI to the development of mathematical problem-solving strategies; (3) the role of GenAI in facilitating mathematical critical thinking;

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(4) the influence of students' AI literacy levels on the quality of technology utilization; and (5) the transformation of the teacher's role alongside the strengthening of academic ethics and scholarly integrity. Through this systematic methodological design, the study generated an in-depth understanding of the authentic integration of GenAI in Phase F Mathematics learning and its impact on the interactions among students, teachers, mathematical knowledge, and digital technology. Interview transcripts were coded deductively using these five dimensions and inductively for emerging patterns. The main interview findings are summarized in Table 2, and representative excerpts are presented in the Results section using the participant codes described above.

RESULT

The results are presented according to the five analytical dimensions, and each dimension integrates observation, interview, and documentation data. Table 2 summarizes the main interview findings for each dimension, while representative interview excerpts and screenshots of student AI interactions are presented in the corresponding subsections.

Table 2. Summary of Interview Findings

Dimension	Informant	Main interview findings
Dialogic interaction and conceptual understanding	T	AI was positioned as a thinking partner, not a substitute for instruction. Students were encouraged to ask AI for simpler explanations, additional examples, comparisons of solution methods, and clarification of difficult steps, and to interpret and verify the responses
Problem-solving strategies	S, T	Students reported that AI helped them determine the first step, gave hints, and divided complex problems into smaller stages. The teacher required students to compare AI strategies with classroom methods and to verify each step
Mathematical critical thinking	S	Students reported encountering inconsistencies or errors in AI outputs and verified them through recalculation, alternative methods, peer discussion, or consultation with the teacher
AI literacy	T	AI literacy was described as more than operating the platform: it includes understanding AI limitations and formulating purposeful prompts (e.g., asking AI to act as a tutor, give gradual hints, identify errors, or pose guiding questions)
Teacher's role and academic ethics	T	The teacher was concerned about students copying AI answers and therefore required them to explain solutions in their own words, show manual calculations, compare AI responses with their own work, and answer follow-up questions

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1. Formation of Dialogic Interactions between Students and Generative AI as a Thinking Partner in Understanding Mathematical Concepts

Classroom observations of Phase F Mathematics learning at SMA Muhammadiyah Mlati revealed that students had begun to use generative AI as a supporting resource for understanding mathematical concepts perceived as complex. This use was particularly evident when students engaged with topics such as matrices, functions, statistics, and probability, which require not only procedural fluency but also conceptual understanding and logical reasoning. Rather than using AI merely to obtain final answers, students interacted with the technology by asking follow-up questions about the sequence of solution steps, the rationale behind the use of particular formulas, and alternative approaches to solving mathematical problems. The observed interaction demonstrated that students increasingly viewed generative AI as a responsive source of explanation that could provide additional support when the teacher's initial explanation had not yet fully addressed their individual learning needs. In this context, AI served as an additional learning resource that enabled students to revisit difficult concepts and explore mathematical ideas at their own pace.

The observation findings were reinforced by interviews with the mathematics teacher. The interview data indicated that generative AI was deliberately positioned as a thinking partner rather than a substitute for classroom instruction. According to the teacher's explanation, students were encouraged to ask AI to explain concepts using simpler language, provide additional examples, compare different solution methods, or clarify particular steps that remained difficult to understand. The teacher also emphasized that AI-generated explanations could not be accepted without examination because students were expected to interpret and verify the information obtained. Thus, the interview data provide an important explanation of how the observed student-AI interactions were pedagogically interpreted: the use of AI was considered meaningful when students remained actively involved in questioning, interpreting, and checking the mathematical information provided by the technology. This interpretation is illustrated by the following excerpt from the teacher interview:

> *T : I position AI as a thinking partner. Students can ask for simpler explanations or additional examples, but they must still check and verify the AI's responses against the mathematical material and concepts they have learned*

Documentation of the learning process further supported these findings through screenshots of students' interactions with generative AI and samples of their mathematical work. The documented interactions contained initial questions, requests for clarification, follow-up questions, corrections, requests for alternative explanations, and demands for similar examples. When these documentation findings are considered alongside the observation and interview data, they indicate a shift from using digital technology as a one-way information retrieval tool toward a more interactive and dialogic learning process. Therefore, generative AI functioned as a dialogic thinking partner insofar as students used it to ask questions, test understanding, seek clarification, reconsider mathematical ideas, and reflect on the reasoning involved in solving mathematical problems.

The documented interactions also revealed how dialogic interactions between students and generative AI were formed. The interactions generally developed through a recurring cycle: (1) an initial prompt in which students stated a problem or a point of confusion; (2) an AI response offering an explanation, a hint, or a solution; (3) follow-up prompts in which students requested clarification, simpler language, alternative methods, or similar examples; and (4) students' re-articulation and verification of the explanation against classroom

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concepts or manual calculations. The depth of this cycle differed depending on whether the interaction occurred with or without teacher support.

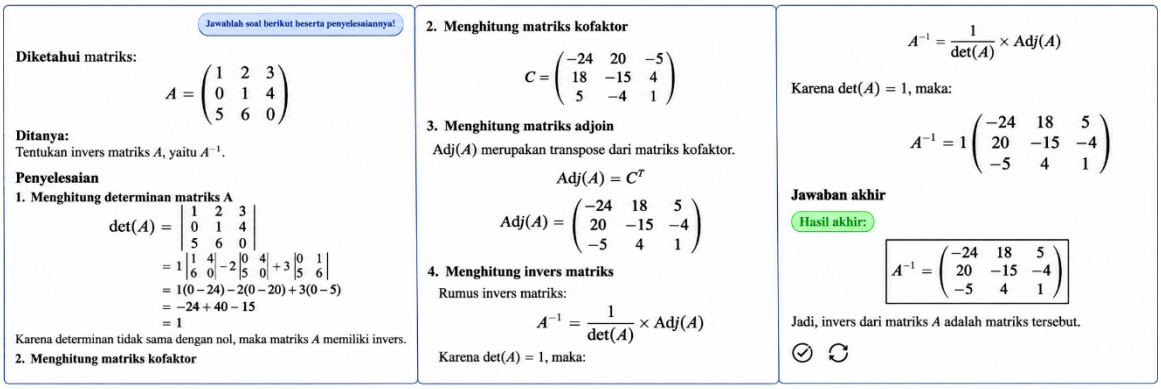


Figure 1. Figure 1. Example of student interaction with generative AI without teacher support on the topic of Matrix Inverses

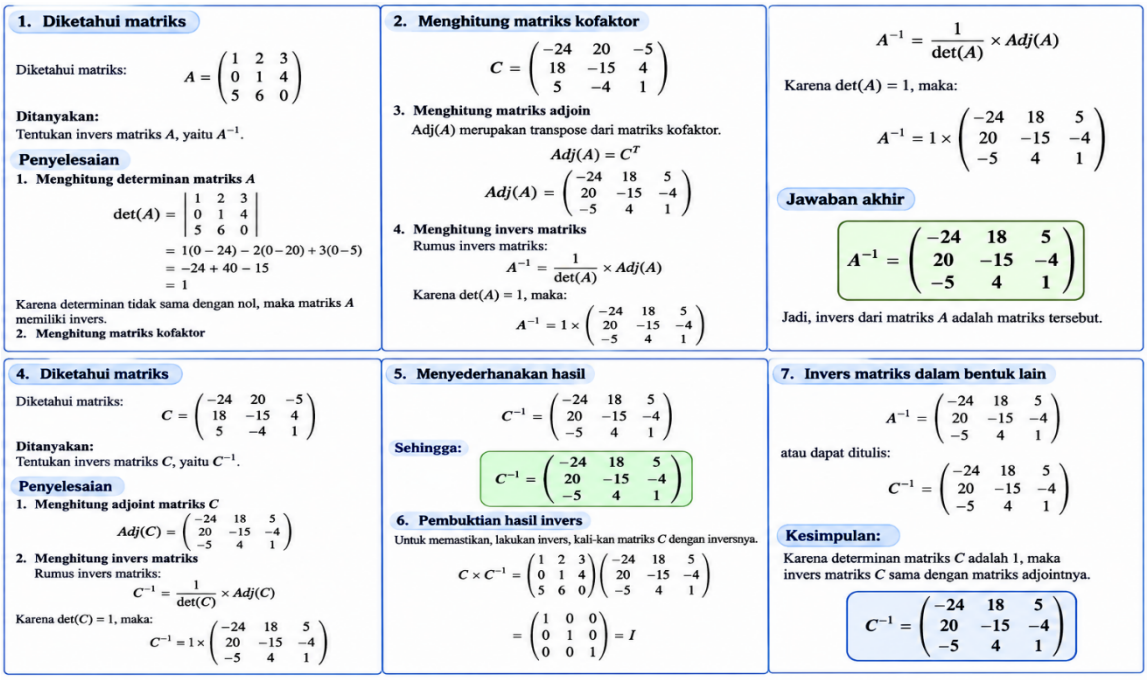


Figure 1. Example of a Student-Generative AI Interaction with Teacher Support (S1, topic: Matrix Inverses; translated from Indonesian)

Figure 1 illustrates student-initiated interactions without teacher guidance, in which students tend to use direct prompts to obtain answers or solutions to mathematical problems from AI. Consequently, these interactions are primarily oriented toward final answers and involve relatively few follow-up questions to explore the underlying mathematical reasoning processes. In contrast, Figure 2 illustrates interactions after the teacher guides students to use AI as a tutor. In this situation, students begin to formulate more purposeful prompts, such as requesting step-by-step explanations, solution hints, alternative methods, error analysis, and feedback on the solution steps they have completed. This difference in interaction patterns indicates that dialogic exchanges do not emerge automatically merely through access to AI. Rather, they develop through students' follow-up questions and are reinforced by teacher scaffolding that encourages explanation and verification. Thus, this process supports conceptual understanding, exploration of problem-solving strategies, and solution

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verification. Rather, they develop through students' follow-up questions and are reinforced by teacher scaffolding that encourages explanation and verification.

Concrete evidence of this scaffolding was observed during classroom sessions when the teacher circulated among student groups and intervened verbally whenever students merely copied AI outputs. For instance, upon noticing a student recording an inverse matrix solution directly from ChatGPT, the teacher prompted verbally: "Do not just copy the final matrix ask the AI why the determinant must be calculated first, and then prove to me manually that multiplying matrix A by A^{-1} yields the identity matrix". Such verbal prompts redirected students from passive answer-seeking toward active dialogic questioning and mathematical verification. Thus, this process supports conceptual understanding, exploration of problem-solving strategies, and solution verification.

2. Generative AI Supports the Development of Mathematical Problem-Solving Strategies

Classroom observations indicated that students used generative AI to explore and compare different strategies for solving mathematical problems. When confronted with complex or unfamiliar problems, some students asked AI to provide initial hints, identify possible starting points, or explain problems through alternative representations. The strategies explored through AI included algebraic procedures, tabular representations, graphical approaches, symbolic reasoning, and contextual explanations. This pattern demonstrated that generative AI was not limited to producing a single answer but could expose students to the possibility that mathematical problems might be approached through several strategies. The observation therefore suggests that interaction with AI potentially expanded students' awareness of mathematical flexibility and encouraged them to consider relationships among different forms of representation and reasoning.

This finding was further clarified through student interviews. The interview data revealed that generative AI was particularly useful when students experienced difficulty determining the first step in a problem-solving process. Several students reported that AI helped reduce their initial confusion by providing hints or dividing complex problems into smaller stages. Other students used AI to request alternative explanations when the first explanation did not correspond to their preferred way of understanding. These interview findings provide evidence that students did not always use AI simply to obtain complete solutions; rather, some students used it to overcome specific cognitive obstacles encountered during problem solving. At the same time, the teacher's interview emphasized that students remained responsible for understanding and verifying every step generated by AI. Students were therefore encouraged to compare AI-generated strategies with classroom methods, identify the mathematical principles underlying each procedure, and determine whether the resulting answer was consistent with the conditions of the problem. The following excerpts illustrate these views:

T : I ask students to compare the solution steps generated by AI with the methods learned in class. They must be able to explain the mathematical concepts underlying each procedure, the rationale behind the choice of formulas, and the calculations themselves. I also require them to verify that the final result accurately aligns with the conditions of the problem.

S1 : I compare the formulas and solution steps provided by AI with the materials explained by the teacher. If I find any differences, I try to understand why AI uses a particular approach.

S2 : I carefully recheck the calculations, especially when a problem involves multiple steps. I also make sure that the final answer is consistent with the given information and what the problem asks.

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S3 : I do not immediately trust every answer generated by AI. I compare its explanations with my textbook or class notes. If I am still uncertain, I ask the teacher for clarification.

Documentation of students' written work and AI interactions provided additional evidence regarding how AI-generated strategies were transformed into mathematical solutions. Some students were able to reinterpret AI explanations and reconstruct solutions using their own words, reasoning, and mathematical representations. However, other students tended to reproduce AI-generated procedures without adequately explaining the rationale behind particular steps. The strategies explored through AI included algebraic procedures, tabular representations, graphical approaches, symbolic reasoning, and contextual explanations. For example, during a lesson on function transformations and calculus optimization, classroom observations captured several students who struggled with purely symbolic derivatives asking GenAI to illustrate how the function's gradient changed using a tabular comparison of x and $f'(x)$ values alongside a step-by-step verbal explanation of the turning points. Similarly, when solving systems of linear equations using matrices, another group of students prompted the AI to compare the Cramer's rule approach with the Gauss-Jordan elimination method so they could identify which procedure required fewer arithmetic steps. This pattern demonstrated that generative AI was not limited to producing a single answer but could expose students to the possibility that mathematical problems might be approached through several strategies.

The combination of interview and documentation findings indicates that the contribution of generative AI to mathematical problem solving was not automatic. Although AI could broaden the range of strategies available to students, its educational value depended on students' ability to process, understand, adapt, and verify the information received. Accordingly, generative AI supported mathematical problem-solving development most effectively when its use was embedded in learning activities requiring explanation, comparison, justification, and reflection.

3. Interaction with Generative AI Promotes the Development of Mathematical Critical Thinking

Classroom observations demonstrated that the use of generative AI encouraged students to engage in activities involving comparison, examination, and evaluation of mathematical solutions. Rather than allowing students to accept AI-generated answers immediately, the teacher explicitly instructed them to verify both the reasoning process and the final results using mathematical concepts that had been studied. In several learning activities, students compared solutions generated by AI with solutions they had independently developed through manual calculations. This comparison encouraged students to identify similarities and differences between approaches, examine the logical consistency of individual steps, and determine whether AI-generated solutions were mathematically valid. The learning process consequently moved beyond the simple acquisition of answers toward a more reflective engagement with mathematical reasoning.

The interview findings provide further insight into this process. Several students reported that they had encountered inconsistencies or errors in answers and procedures generated by AI. These experiences led them to undertake independent verification through recalculation, alternative methods, peer discussion, or consultation with the teacher. The interview data are significant because they show that students' encounters with inaccurate AI outputs became occasions for questioning the reliability of technological information.

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Students were encouraged to consider whether an answer was logically justified, whether the procedure corresponded to the mathematical concept being studied, and whether the final result was reasonable within the context of the problem. Thus, the interview findings explain how students' experiences with AI were interpreted as opportunities to develop evaluative mathematical thinking rather than simply as evidence of technological effectiveness. One student described this experience as follows:

S1 : I asked AI to solve a mathematics problem, but I noticed that one of the calculation steps did not seem correct. I recalculated it independently and compared the result with the method taught by the teacher. After checking, I realized that AI had made an error in the calculation.

S2 : I once received a final answer from AI that was different from my own result. I did not immediately assume that my answer was wrong. I checked the formula, substituted the given values again, and reviewed each calculation step. It turned out that AI had used an incorrect value in one of its steps.

S3 : Sometimes AI provides explanations that look convincing, but the steps do not match the mathematical concepts I have learned. When this happens, I compare the explanation with my textbook and class notes. I also try to solve the problem using another method to determine whether the results are consistent.

Learning documentation further showed comparisons between AI-generated solutions and students' manual work, peer discussions, and confirmation of mathematical reasoning with the teacher. These documented activities strengthened the interpretation emerging from the observations and interviews: critical thinking was reflected not merely in obtaining a correct answer but in questioning information, examining procedures, identifying errors, providing mathematical justification, and evaluating alternative solutions. Therefore, generative AI functioned as a stimulus for mathematical critical thinking when its outputs were treated as objects of inquiry and verification. The findings indicate that the development of critical thinking was closely related to students' continued position as the primary decision-makers in the problem-solving process.

4. Students' AI Literacy Determines the Quality of Generative AI Use in Mathematics Learning

Observations revealed substantial differences in students' ability to use generative AI effectively in mathematics learning. These differences were visible in how students formulated questions, provided instructions, interpreted responses, and continued their interaction with AI. Students who formulated clear, specific, and contextually appropriate prompts generally obtained explanations that were more relevant, systematic, and aligned with their learning needs. In contrast, students who used brief commands such as requesting AI to solve a problem tended to receive answers passively and often did not engage further with the reasoning behind the solution. The observation therefore indicates that access to generative AI alone does not guarantee meaningful learning; rather, the quality of interaction between students and technology influences whether AI functions as a tool for deeper understanding or merely as a mechanism for obtaining immediate answers.

The interview with the mathematics teacher provided a more detailed explanation of these differences. The teacher explained that AI literacy involved more than the technical ability to access and operate an AI platform. Students also needed to understand the potential limitations, inaccuracies, and contextual weaknesses of AI-generated responses. They were expected to evaluate whether an answer was mathematically correct, whether the solution

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procedure was logically justified, and whether the response was relevant to the problem being addressed. The teacher therefore encouraged students to formulate purposeful prompts, for example by asking AI to act as a tutor, provide gradual hints, explain concepts at an appropriate level of difficulty, identify errors in a proposed solution, or pose guiding questions rather than immediately providing final answers. The interview findings consequently help explain why differences in prompt quality observed in the classroom were interpreted as differences in AI literacy rather than merely differences in students' familiarity with technology. The teacher expressed this view as follows:

> *T : In my view, AI literacy extends beyond technical proficiency to include recognizing AI's limitations and evaluating the accuracy, logic, and relevance of its responses. Therefore, I encourage students to use purposeful prompts, such as asking AI to act as a mathematics tutor and provide step-by-step guidance. This enables students to use AI not merely to obtain answers but also to understand concepts, evaluate solution processes, and develop critical thinking skills.*

Documentation of students' interactions with generative AI demonstrated clear differences in the quality and complexity of prompts. Some students continued to rely on direct commands requesting complete answers, whereas others developed more sophisticated prompts requesting alternative solution methods, step-by-step explanations, error analysis, or feedback on their own mathematical reasoning. When triangulated with observation and interview data, these findings suggest that students' AI literacy substantially influenced the quality of their engagement with generative AI. Successful implementation of generative AI in Phase F Mathematics learning therefore depended not only on technological access but also on students' capacity to formulate effective prompts, interpret AI-generated responses, evaluate the accuracy and relevance of outputs, and use the technology critically and responsibly.

5. Generative AI Transforms the Teacher's Role and Requires Stronger Academic Ethics

Classroom observations demonstrated that the presence of generative AI did not eliminate the role of the mathematics teacher; instead, it transformed the nature of that role. The teacher increasingly functioned as a facilitator, learning guide, monitor, and evaluator of students' thinking processes. Rather than serving solely as the primary source of mathematical information, the teacher guided students in determining how AI could be used productively and responsibly. During Phase F Mathematics learning, students were given opportunities to interact with generative AI, but they were also required to explain, justify, and take responsibility for the mathematical solutions they produced. The observation therefore indicates that the teacher's role shifted toward designing learning situations in which AI could expand students' thinking without replacing their cognitive engagement.

The interview findings provided a particularly important explanation of the teacher's role in maintaining students' academic engagement. The teacher expressed concern about excessive or inappropriate use of generative AI, particularly the tendency of some students to copy AI-generated answers without understanding the underlying mathematical reasoning. In response, the teacher required students to explain AI-generated solutions in their own words, demonstrate manual calculations, compare AI responses with their own work, and answer follow-up questions designed to examine conceptual understanding. These interview findings indicate that the teacher's role was not simply to permit or restrict AI use but to establish

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pedagogical conditions under which students remained intellectually responsible for the work they produced. This position is reflected in the following excerpt:

> *T : I require students to explain AI-generated solutions in their own words rather than simply copying the answers. They must also demonstrate their manual calculations and compare their results with those generated by AI. If discrepancies arise, students are expected to explain the reasons behind them. Through follow-up questions, I can assess whether they genuinely understand the mathematical concepts and solution procedures they have use.*

Documentation of classroom activities further indicated that generative AI was positioned as a source of assistance, feedback, and exploration rather than a replacement for students' own thinking. The documented learning activities showed the importance of examining, interpreting, and verifying AI-generated outputs, while the teacher's guidance reinforced students' responsibility for the mathematical reasoning underlying their answers. The triangulation of observation, interview, and documentation data therefore suggests that the integration of generative AI requires a balance between technological innovation and academic ethics. In this context, effective AI-supported Mathematics learning involves not only access to technology but also learning conditions that hold students accountable for their own mathematical reasoning, such as explaining, justifying, and verifying AI-assisted solutions. Generative AI can consequently function as a genuine thinking partner when students remain responsible for interpreting and validating its outputs and when teachers maintain an active role in guiding the learning process.

DISCUSSION

The utilization of Generative AI as a dialogic thinking partner in Phase F Mathematics learning at SMA Muhammadiyah Mlati signifies a paradigm shift from using technology as a one-way information retrieval tool to an interactive, two-way cognitive medium. The research findings indicate that students do not merely use AI to obtain immediate answers; rather, they engage in active dialogue by asking follow-up questions, requesting simplified explanations, and verifying mathematical reasoning across complex topics such as matrices, functions, and probability. This phenomenon reinforces the findings of Kaya and Yavuz (2025) and Pisriwati et al. (2024) , who argued that Generative AI possesses transformative potential in creating personalized learning environments through responsive cognitive scaffolding. This is also seen in the work of Buot et al. (2025), who found that ALEKS as an AI-based learning tool provides meaningful and immediate feedback which enable mastery of math topics among university-level students. Furthermore, these results align with a study by Liu et al. (2026) and Sa'id et al. (2026), which emphasized that interactive dialogues between students and artificial intelligence systems facilitate the independent reconstruction of conceptual understanding. Consequently, AI functions as a medium that expands the space for mathematical dialogue beyond the temporal constraints of traditional classroom instruction.

The capacity of Generative AI to support the exploration of diverse mathematical problem-solving strategies proved to enhance students' cognitive flexibility at SMA Muhammadiyah Mlati. When confronted with complex tasks, students utilized AI to identify initial starting points, examine alternative representations (such as graphical or symbolic forms), and compare various algebraic methods. This supports the findings of Al Darayseh and Mersin (2025) and Nguyen (2025), who revealed that integrating AI into mathematics education enhances mathematical flexibility and assists students in overcoming initial

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cognitive blockages when starting a problem-solving process. However, field observations also uncovered variations where some students still tended to copy procedures without deep conceptual processing. This observation confirms the caution highlighted by Li (2025), stating that exposure to diverse AI-generated strategies does not automatically improve students' procedural fluency unless accompanied by learning tasks that demand independent articulation, reinterpretation, and mathematical justification.

Interaction with Generative AI served as a significant catalyst for developing students' mathematical critical thinking when paired with an appropriate verification pedagogy. Occasional errors or inaccuracies in AI-generated responses were strategically leveraged by the teacher at SMA Muhammadiyah Mlati as teachable moments, prompting students to perform manual recalculations, logical analyses, and proofs. This outcome aligns with research by Nugroho et al. (2018) and Kintoko et al. (2025), who found that the imperfections of AI outputs can trigger healthy academic skepticism and critical thinking, preventing students from passively accepting information. Moreover, these findings reinforce the conceptual framework proposed by Walter (2024), which asserts that critical thinking in the AI era develops not when technology provides flawless answers, but when technological outputs are treated as objects of comprehensive mathematical inquiry, critique, and reflection.

This study reveals that students' level of AI literacy serves as a pivotal factor determining the quality and depth of Generative AI utilization in mathematics learning. Students with proficient AI literacy formulated specific, context-rich prompts such as asking AI to act as a tutor or provide step-by-step hints thereby receiving systematic explanations, whereas students with lower literacy relied on brief commands that resulted in passive learning. This finding is highly relevant to the work of Serra and Oliveira (2025) and Torkestani et al. (2025), who emphasized that the effectiveness of AI-assisted learning depends substantially on prompt engineering skills and a critical understanding of the technology's limitations. This concept of AI literacy in mathematics education underscores the argument of Qian (2025) that AI education must extend beyond operational technical skills to encompass the ability to critically evaluate the relevance, logic, and mathematical accuracy of AI-generated outputs.

The presence of Generative AI in Phase F Mathematics classrooms did not diminish the role of the teacher, but rather transformed it from a primary source of knowledge into a cognitive facilitator and guardian of academic ethics. Teachers played a vital role in designing learning tasks that required students to articulate AI-generated solutions in their own words and defend their reasoning before the class. This shifting role confirms the findings of Kyambade et al. (2025) and Li et al. (2026), who asserted that the successful integration of AI in schools relies heavily on human-in-the-loop pedagogy, where educators retain authority over students' cognitive and moral evaluation. Furthermore, research by Papaneophytou and Nicolaou (2025) corroborates that AI operates most effectively as a learning aid when teachers actively guide students in synthesizing technological outputs with human reasoning.

Overall, the integration of Generative AI into Phase F Mathematics learning at SMA Muhammadiyah Mlati illustrates how technological innovation, mathematical reasoning, and attention to academic ethics can be brought together. Employing AI as a thinking partner enriched students' cognitive learning experiences, particularly in clarifying concepts, exploring strategies, and verifying solutions. The findings also show that the teacher deliberately structured AI use around accountability practices, namely requiring students to explain AI-generated solutions in their own words, demonstrate manual calculations, and answer follow-up questions. These practices created learning conditions that emphasized students' responsibility for their own mathematical reasoning and supported more autonomous

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learning. However, because this study did not directly examine students' honesty or responsibility as values, it cannot be concluded that the use of generative AI itself cultivated these values; whether accountability-oriented AI use contributes to the development of academic integrity over time requires further investigation. The implications of this study support the conclusions of Manousou (2025), who contended that AI-driven digital transformation in education must be oriented toward empowering learner autonomy and intellectual integrity rather than replacing human thought with instant automation. Thus, the implementation of Generative AI at SMA Muhammadiyah Mlati provides an empirical illustration of how advanced technologies can be utilized wisely and meaningfully to foster holistic, critical, and ethical mathematics learning.

CONCLUSION

This study concludes that generative AI has significant potential to support students' conceptual understanding, mathematical problem-solving strategies, and critical thinking in Phase F Mathematics learning at SMA Muhammadiyah Mlati. Students increasingly use generative AI as a dialogic learning resource to ask questions, seek clarification, explore alternative strategies, and evaluate mathematical reasoning. However, its effectiveness depends on students' AI literacy, particularly their ability to formulate effective prompts, critically evaluate AI-generated outputs, and verify mathematical solutions. The integration of generative AI also transforms the teacher's role into a facilitator, guide, and evaluator who ensures that technology supports rather than replaces students' cognitive engagement. Therefore, schools should develop ethical AI-use guidelines, strengthen students' AI literacy and critical mathematical reasoning, and enhance teachers' capacity to integrate AI into meaningful learning. This study was limited to a single school and a small number of participants, and it did not directly measure students' values such as honesty and responsibility. Future research should examine the long-term effects of generative AI on students' mathematical achievement, autonomy, creativity, and critical thinking through broader and longitudinal studies.

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