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Integrating Artificial Intelligence in Mathematics Education: A Systematic Literature Review on Teachers' Practices

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Abstract

This study is motivated by the need to improve the quality of mathematics learning in the digital era, where the complexity of subject matter and low student learning motivation require innovative and adaptive approaches. This study aims to analyze the contribution of AI utilization by teachers in improving the mathematics learning process, particularly through the development of technological and pedagogical competencies. The research employs a qualitative approach using a systematic literature review, examining research findings published between 2023 and 2025. The results indicate that continuous training and mentoring play a crucial role in enhancing teachers' technological literacy, which in turn improves their ability to integrate AI into learning media and instructional modules in a more creative and adaptive manner. The findings also show that AI improves teaching time efficiency, facilitates the identification of students' learning difficulties, strengthens critical thinking skills, and reduces mathematics anxiety. The implications of this study emphasize that the successful implementation of AI largely depends on teachers' readiness through sustained digital competence development, enabling AI to function as a catalyst for creating innovative, human-centered, and 21st-century competency-oriented mathematics learning.

Keywords

AI in Education, Digital Competence, Educational Technology, Mathematics Learning, Teacher Development.

1. Introduction

Technological developments in the era of the Industrial Revolution 4.0 and Society 5.0 have significantly transformed the educational paradigm. Artificial Intelligence (AI) technology is no longer utilized solely in industrial, economic, and public service sectors, but has also become an integral part of modern learning processes. In the context of implementing the *Merdeka* Curriculum, teachers are required to assume roles beyond mere transmitters of knowledge, acting instead as facilitators who are capable of leveraging technology to support competency-based learning and the development of 21st-century skills, such as critical thinking, creativity, communication, and collaboration (Handini, 2024; Jamalullel & Nasehudin, 2025). At the same time, mathematics is often perceived as a difficult and intimidating subject by students, thereby necessitating learning innovations through adaptive and advanced technology-based approaches.

Mathematics is a fundamental discipline that plays a crucial role in developing students' reasoning, logic, and analytical abilities. However, empirical evidence indicates that many students struggle to understand abstract mathematical concepts due to teacher-centered instructional practices and limited opportunities for exploration. The use of AI offers transformative potential by providing more interactive and adaptive learning environments tailored to students' individual needs (Badri, 2024; Prayogi et al., 2025). AI technology enables content personalization, automated assessment, and real-time learning data analysis to identify students' learning difficulties (Buton et al., 2025). Elfani et al. (2025) demonstrate that integrating AI into mathematics instruction can enhance conceptual understanding, strengthen motivation for learning, and accelerate mathematical problem-solving.

The application of AI in learning is aligned with constructivist approaches, instructional differentiation, and deep learning–based learning models. AI is able to support teachers in designing learning experiences that enable students to construct their own understanding through algorithmic modeling and interactive simulations (Ishartono et al., 2024). Technologies such as GPT-based AI have been proven to simplify complex mathematical concepts into more concrete explanations, while AI-driven deep learning systems are capable of enhancing students' critical, logical, and systematic thinking skills (Hayati et al., 2025). This indicates that AI does not merely function as a technological support tool, but also serves as a pedagogical instrument that promotes independent, reflective, and reasoning-based learning.

Despite the significant potential of AI, its implementation in Indonesia continues to face substantial challenges (Patty & Lekatompessy, 2024). Empirical evidence indicates that teachers' readiness to utilize AI remains relatively low, primarily due to limited technological literacy, insufficient professional training, and unequal access to supporting infrastructure, particularly in non-urban areas (Siregar et al., 2025). While existing studies have largely focused on the potential and impact of AI applications on students' learning outcomes (Afifah et al., 2025), they tend to overlook the critical role of teachers as the main facilitators of AI adoption in mathematics learning, especially within the context of the Merdeka Curriculum. Moreover, research that systematically explores practical implementation strategies and evidence-based solutions to address barriers in integrating AI into mathematics instruction remains limited. This gap highlights the need for studies that comprehensively examine teachers' competencies, pedagogical practices, and implementation approaches in leveraging AI to enhance the mathematics learning process.

This study offers novelty by developing a systematic literature review that specifically examines teachers' use of AI to improve the quality of mathematics learning. The research focus extends beyond the impact of AI on students to explore teacher readiness, forms of technological intervention implemented, and strategies

for optimizing AI implementation in accordance with the Indonesian educational context. The uniqueness of this study lies in its in-depth analysis of practical implementation rather than merely theoretical potential, as well as in the formulation of empirically grounded recommendations relevant to supporting innovative mathematics learning in the digital era.

The research problems addressed in this study include: (1) the forms of training and competency development for teachers in the use of AI, (2) the development of AI-based instructional media and teaching modules, and (3) the impact of AI on the mathematics learning process and learning outcomes. Based on these problem formulations, the objectives of this study are to analyze teacher training and competency development in AI utilization, the development of AI-based instructional media and teaching modules, the impact of AI on the mathematics learning process and learning outcomes, and to formulate strategic recommendations to support mathematics learning that is more adaptive, engaging, and responsive to contemporary educational needs.

The findings of this study are expected to contribute theoretically to the development of educational technology research, while also serving as a practical reference for teachers, policymakers, and educational institutions in designing implementative and effective AI-based mathematics learning models. The results are also projected to encourage the emergence of technology-based teacher training policies, strengthen school readiness in adopting AI, and support the creation of a more interactive and collaborative mathematics learning ecosystem capable of enhancing educational quality in the digital era. Thus, this study plays an important role in supporting educational transformation toward a system that is more adaptive to technological developments and the needs of future generations.

2. Literature Review

2.1. AI Integration in Education

The utilization of Artificial Intelligence (AI) in education has continued to expand as part of the digital transformation in the era of the Industrial Revolution 4.0 and Society 5.0. AI plays a role in providing adaptive learning systems that are able to tailor instructional content to individual students' needs through real-time analysis of learning data. A study by Badri (2024) shows that AI enables personalized learning, improves teachers' time efficiency, and expands technology-based learning resources. Meanwhile, research by Buton et al. (2025) reveals that GPT-based AI tools can reduce the complexity of mathematical concepts into explanations that are easier to understand, thereby contributing to improved student comprehension.

Previous studies have consistently highlighted the positive role of AI in enhancing the quality of mathematics learning, although they emphasize different dimensions of its impact. Elfani et al. (2025) demonstrate that the application of AI-based deep learning significantly improves students' critical thinking and problem-solving skills, positioning AI not merely as a technological aid but as a pedagogical partner aligned with constructivist and meaningful learning approaches. In contrast, Yeo et al. (2024) provide a broader synthesis, emphasizing AI's overall potential to strengthen both conceptual understanding and the development of 21st-century skills in mathematics education. From the teacher perspective, Egara and Mosimege (2024) focus on awareness and usage, revealing that mathematics teachers who are familiar with and actively use ChatGPT perceive it as an effective tool for improving teaching efficiency and student engagement, although its adoption remains uneven. Meanwhile, Kumar et al. (2025) extend the discussion to the higher education context, finding that AI adoption fosters knowledge sharing among educators and students, highlighting AI's role in strengthening collaborative learning environments. Collectively, these studies indicate that while prior research has

documented AI's benefits across student outcomes, teacher perceptions, and institutional collaboration, differences remain in focus, context, and level of analysis, underscoring the need for more integrative research that bridges pedagogical impact, teacher facilitation, and implementation practices in mathematics learning.

2.2. Teacher Competence in the Utilization of AI

Although AI has substantial potential in education, its implementation depends heavily on teachers' competence as the primary facilitators of learning. Ishartono et al. (2024) found that low levels of teachers' technological literacy, limited infrastructure, and insufficient training constitute the main barriers to the use of AI in mathematics education. Studies by Patty and Lekatompessy (2024) indicate that intensive training and practice-based mentoring are effective in enhancing teachers' skills in utilizing AI to develop instructional materials, analyze student learning outcomes, and design interactive learning activities.

Efforts to improve teacher competence are also reported by Hayati et al. (2025), who show that teachers participating in AI workshops experience a significant increase in their ability to integrate technology into the learning process. This finding suggests that the success of AI utilization is determined not only by the technology itself but also by teachers' readiness and pedagogical capacity to adapt it to the curriculum context and students' needs (Razilu & Zila, 2025). Accordingly, the literature indicates that teacher competence serves as a critical moderating factor in determining the effectiveness of AI use in mathematics learning. The effectiveness of AI implementation is strongly influenced by teachers' competence in operating and integrating technology into instructional strategies (Fadhilah & Nuriza, 2025).

3. Methods

The research method used in this study is a qualitative approach based on a systematic literature review, aimed at identifying, evaluating, and interpreting findings from studies on the use of Artificial Intelligence (AI) by teachers to enhance the mathematics learning process (Moleong, 2017). This approach was chosen because it enables a deep and comprehensive understanding of the research phenomenon through critical analysis of diverse scholarly sources (Warman, 2024). The research process was conducted through several systematic stages, beginning with the formulation of research questions focused on the forms of AI utilization by teachers in mathematics instruction, its impact on the quality of the learning process, and the challenges and solutions in its implementation.

Subsequently, a literature search and selection were carried out using the author's relevant references, comprising scientific journals, conference articles, and community service reports published during the 2023–2025 period, with inclusion criteria that specifically addressed the role of teachers in the use of AI in mathematics learning. The literature search was conducted systematically using a predefined search strategy to identify relevant studies on the use of Artificial Intelligence (AI) by teachers in mathematics learning. Keywords such as "artificial intelligence," "AI in education," "mathematics learning," "teacher competence," and "AI-assisted instruction" were applied using Boolean operators (AND, OR) to refine the search results. The search process was carried out in reputable academic databases, primarily Google Scholar, complemented by ERIC (Education Resources Information Center) and the Directory of Open Access Journals (DOAJ) to ensure broad and reliable coverage of peer-reviewed literature. These databases were selected for their strong relevance to educational research and technology-enhanced learning, enabling the study to capture interdisciplinary perspectives while minimizing publication bias.

The next stage involved evaluating the credibility and conducting thematic analysis of the selected literature by grouping findings into consistently emerging

themes, such as the development of learning media, material personalization, automated assessment, and enhancement of teacher competencies through AI workshops or training (Fadli, 2021). The results of the thematic analysis were then synthesized to address the research questions, thereby producing a more comprehensive understanding of the mechanisms of AI implementation by mathematics teachers, its effectiveness in improving student interactivity and comprehension, and strategies for optimizing its use in the future.

4. Results

4.1. Training and Enhancement of Teacher Competencies in the Use of AI

The integration of AI in mathematics learning requires teachers to possess readiness that extends beyond pedagogical understanding to include adequate technological competence (Wang et al., 2023). At the initial stage, many teachers face difficulties in operating various AI tools due to limited technical knowledge and experience. This condition reflects a gap between the demands of 21st-century learning and teachers' competencies, particularly in designing adaptive and innovative instructional approaches. AI, which offers potential for personalization and automation in learning processes, cannot be optimally utilized if teachers lack fundamental skills in its application (Hayati et al., 2025).

The implementation of intensive training and mentoring is crucial for building teachers' confidence in using AI more productively. After participating in competency development programs, teachers begin to integrate AI into the design of instructional tools such as lesson plans, teaching modules, and student worksheets more efficiently. Moreover, training encourages teachers to understand deep learning, prompting them to focus on strengthening students' conceptual understanding rather than merely memorizing formulas (Lamrabet et al., 2025). Teachers also start adapting AI to support students' independent exploration as part of discovery-based learning strategies (Ishartono et al., 2024).

As technological competence improves, teachers' perspectives on AI also evolve. Whereas AI was previously viewed merely as a technical tool, it is increasingly understood as a cognitive partner that supports teachers in instructional planning and pedagogical decision-making. AI is utilized to enrich learning materials, diversify teaching methods, and provide alternative solutions to students' learning difficulties. This transformation in mindset represents a critical turning point, as successful AI integration largely depends on teachers' willingness to adopt technology as an integral part of their professional practice.

Nevertheless, strengthening teachers' technological competence cannot be achieved through one-time or short-term training alone. The development of technological literacy requires a continuous process supported by collaboration within teacher communities, such as subject teacher forums (*Musyawarah Guru Mata Pelajaran*/MGMP), which serve as platforms for sharing experiences and best practices (Hakim & Abidin, 2024). Integrating AI-related content into teacher professional education is also a strategic step in preparing future educators to meet the demands of the digital era. Through systematic and sustainable competency development, teachers can adapt more quickly and effectively to technological change (Soleh, 2025).

Thus, enhancing teacher competencies through continuous training and mentoring is a key determinant of successful AI implementation in mathematics learning. The higher the level of teachers' technological literacy, the more optimally AI can be utilized to strengthen the learning process and increase student engagement. AI integration not only improves teaching effectiveness but also opens opportunities for teachers to act as learning innovators, thereby supporting the comprehensive achievement of 21st-century education goals.

Table 1. Improvement of Teacher Competencies in the Utilization of AI

No	Training Stages	AI Tools Used	Impact on Teachers
1	Basic workshop	ChatGPT, Gemini	Understanding AI concepts
2	Mentoring	Canva AI	Ability to create learning media
3	Advanced training	Deep Learning Module	Developing teaching modules
4	AI-based MGMP	GPT AI	Teacher collaboration
5	Continuous evaluation	AI Quiz Builder	Automated assessment

Table 1 shows that training and the enhancement of teacher competencies are key factors in the successful implementation of AI in mathematics learning, as the effectiveness of technology integration is largely determined by teachers' readiness and ability to adapt to digital developments. Therefore, continuous and community-based training is the most effective strategy for strengthening pedagogical capacity while simultaneously improving teachers' technological skills, enabling optimal AI implementation, supporting innovative learning processes, and contributing to sustainable improvements in student learning outcomes.

4.2. Development of AI-Based Learning Media and Instructional Modules

The use of artificial intelligence in developing mathematics learning media presents significant opportunities for innovation, particularly in delivering content in a visual, interactive, and contextual manner. Through AI, teachers can design representations of complex mathematical concepts in simpler forms that are easier for students to understand (Williamson et al., 2019). AI-based tools also enable the creation of learning materials that are more aesthetically engaging and contextually relevant to 21st-century education. The integration of technologies such as three-dimensional simulations through interactive media further assists students in more concrete understanding spatial and geometric concepts, especially for those with visual learning preferences (Sinulingga, 2024).

In addition to producing visual media, AI supports the design of problem-based learning scenarios oriented toward real-world applications. Teachers can develop questions and learning activities that not only require conceptual understanding but also foster critical thinking by applying mathematics in authentic contexts. This approach makes mathematics more dynamic and meaningful, as students are not merely passive recipients of information but actively construct knowledge through problem-solving activities that are relevant to their social and cultural environments (Yuriananta & Asteria, 2024).

Furthermore, AI enables the development of adaptive, differentiated instructional modules tailored to students' abilities and learning pace. This technology can analyze learners' needs, adjust the difficulty level of the material, and provide automated feedback to support continuous learning. Such an approach aligns with the principles of the *Merdeka Curriculum*, which positions students as active subjects of learning with diverse needs and potentials (Naufal et al., 2024). Despite the efficiency and convenience offered by AI, teachers remain central in ensuring the quality and relevance of instructional materials. AI-generated content must be curated and edited by teachers to ensure alignment with the curriculum, learning outcome indicators, and pedagogical context. In this regard, AI functions as a cognitive partner that enhances teachers' professional capabilities rather than replacing their role in the educational process (Aly, 2025).

The use of AI in developing mathematics learning media and instructional modules can enhance the quality of teaching and learning by presenting materials that are more engaging, relevant, and aligned with students' needs. When applied optimally and supported by adequate pedagogical competence and digital literacy among teachers, AI technology can serve as a key driver in transforming

mathematics education toward a more modern, effective, and competency-based learning model suited to 21st-century demands.

Table 2. Development of AI-Based Media in Mathematics Learning

No	Form of Utilization	Tools AI	Benefits
1	Visual media design	Canva AI	Engaging learning materials
2	Concept simulation	AR	Abstract concept understanding
3	Contextual problem design	ChatGPT	P5, ethnomathematics
4	Differentiated instructional modules	Adaptive Learning	Tailored to student abilities
5	Automated assessment	AI Quiz Builder	Instant analysis

Based on Table 2, the application of AI in mathematics education significantly encourages the development of more innovative learning media and instructional modules, thereby strengthening the connection between theoretical concepts and students' real-life experiences. This technology not only enhances teachers' creativity in designing learning experiences but also enables more adaptive, interactive, and engaging learning processes that align with learners' characteristics and individual needs. Consequently, AI acts as a catalyst for pedagogical transformation, making mathematics more accessible, relevant, and enjoyable for students.

4.3. The Impact of AI on the Process and Outcomes of Mathematics Learning

The use of Artificial Intelligence (AI) in mathematics education significantly improves the quality of the learning process. Teachers benefit from greater ease in preparing instructional materials, designing assessments, and mapping students' learning needs in a faster and more systematic manner (Fahlena et al., 2025). Time that is usually spent on lesson planning or administrative evaluation can be redirected toward more meaningful activities, such as providing direct guidance to students or conducting dialog-based assessments (Sabariah et al., 2024). Consequently, AI enables teachers to focus more on pedagogical interaction, learning support, and character development, making the learning process more effective, structured, and responsive to individual student needs (Syaukani et al., 2025).

For students, AI-based learning increases interest and motivation in mathematics, a subject often perceived as difficult and unengaging (Elfani et al., 2025). AI technology transforms abstract concepts into interactive visualizations, making learning materials easier to understand and relate to everyday contexts. Beyond serving as a technical tool, AI acts as a medium that stimulates curiosity and enhances student engagement in the learning process. This aligns with the demands of 21st-century learning, which emphasize critical thinking, creativity, and problem-solving skills (Adrias & Zulkarnaini, 2025).

Another advantage of AI lies in its ability to provide rapid and automated feedback on student performance. Teachers can identify learning difficulties at an early stage and implement appropriate interventions in real time (Darlian et al., 2025). This approach supports adaptive learning systems that adjust to students' learning pace and styles, thereby optimizing learning outcomes. At the primary education level, AI also helps create a more enjoyable learning environment and reduces mathematics anxiety, which has long been a psychological barrier for many students (Dinata et al., 2025).

Nevertheless, maximizing the positive impact of AI still requires the active role of teachers as the primary facilitators of learning (Mubarik et al., 2024). Technology must be used wisely and proportionately, rather than becoming the sole source of knowledge (Yunita & Gunawan, 2025). Teachers serve as regulators of AI use to

ensure alignment with educational goals and to prevent dependency or reduced student creativity in independent thinking (Elfani et al., 2025). Moreover, effective integration of technology in learning must be supported by clear regulations, strong monitoring systems, and enhanced digital literacy to ensure that its implementation remains consistent with moral and ethical values in education (Ishartono et al., 2024).

AI serves as a strategic partner for teachers in improving the quality of both the learning process and learning outcomes in mathematics. Its use not only strengthens technical aspects such as time efficiency and instructional delivery but also enhances students' active participation and fosters a more human-centered learning atmosphere. When managed appropriately and grounded in strong pedagogical principles, AI can enable a transformation of mathematics education that is more adaptive, collaborative, and responsive to students' developmental needs in the digital era. Table 3 illustrates the impact of AI on the learning process.

Table 3. The Impact of AI on Learning Processes and Outcomes

No	Impact Subject	Form of Subject	Indicator
1	Teachers	Work efficiency	Reduced preparation time
2	Students	Learning motivation	Increased learning enthusiasm
3	Learning process	Interactive and adaptive	Enhanced collaboration
4	Learning outcomes	Improved critical thinking	Higher evaluation scores
5	Classroom Environment	More enjoyable	Reduced mathematics anxiety

In general, the use of AI in mathematics learning significantly improves the quality of learning processes and student learning outcomes. This technology enhances teachers' pedagogical effectiveness by simplifying administrative tasks and facilitating the development of more relevant and targeted instructional materials. At the same time, AI provides students with a more interactive, adaptive, and engaging learning experience, thereby encouraging active participation, improving conceptual understanding, and reducing anxiety toward mathematics. Thus, the integration of AI in learning not only supports improved teacher performance and student motivation, but also plays a crucial role in fostering 21st-century competencies such as critical thinking, creativity, and problem-solving skills that are essential for addressing the challenges of the digital era.

5. Discussion

The integration of Artificial Intelligence (AI) in mathematics learning shows positive outcomes, particularly after teachers receive appropriate training and mentoring. In the initial stage, many teachers experience difficulties in using technology due to limited experience and low levels of digital literacy (Karanjakwut & Sripicharn, 2024). However, after participating in competency enhancement programs, teachers begin to understand AI not merely as a technical tool, but also as an innovative medium that supports the teaching process. This shift is crucial, as the success of AI utilization in learning is largely determined by teachers' readiness to adapt technology effectively and in accordance with students' needs (Wang et al., 2023).

The analysis indicates that continuous training significantly increases teachers' confidence in integrating AI into instructional tools (Lamrabet et al., 2025). Teachers become more capable of developing lesson plans, teaching modules, and AI-based interactive media, and begin to apply discovery-based learning strategies that emphasize conceptual understanding. As technological competence improves, teachers also become more open to collaboration and the sharing of best practices

through professional communities such as MGMP, which ultimately accelerates digital transformation in the mathematics learning process.

In practice, AI makes a tangible contribution to the development of learning media and instructional scenarios that are more engaging, visual, and aligned with students' real-life contexts (Wiliamson et al., 2019). This technology simplifies complex mathematical concepts into forms that are easier to understand, while also encouraging students to think critically through problem-solving activities grounded in real-world situations (Rane, 2023). AI further supports the development of adaptive teaching modules that adjust to students' learning pace and styles, thereby strengthening the *Merdeka Curriculum's* principle of differentiation. As a result, mathematics learning becomes more dynamic and relevant for learners.

The impact is felt not only by teachers but also by students. The use of AI has been shown to increase students' motivation and active participation, reduce boredom, and create a more enjoyable learning atmosphere (Liu, 2020; Minn, 2022). Technology facilitates rapid and accurate feedback, enabling teachers to identify learning difficulties early and implement timely interventions. For elementary school students, the presence of AI even helps reduce mathematics anxiety, a long-standing barrier to conceptual understanding (Algani, 2024).

These findings imply that AI can meaningfully enhance mathematics pedagogy by enabling more adaptive, interactive, and student-centered learning, provided it is guided by strong pedagogical judgment. At the same time, AI integration reshapes teacher professionalism, requiring continuous professional development, technological literacy, and reflective practice to ensure that technology strengthens the teacher's central role in the learning process (Ding et al., 2024). Nevertheless, optimizing the use of AI still requires teachers to play an active role as the primary controllers of the learning process. AI must be used wisely and should not replace teachers' pedagogical functions. Teacher involvement is essential to ensure that AI-generated content remains relevant, aligned with the curriculum, and does not diminish students' independent thinking skills. With strengthened technological competence and adequate regulatory support, AI integration has the potential to create mathematics learning that is more effective, human-centered, and oriented toward the development of 21st-century competencies. Thus, AI is not merely a supporting tool but a catalyst for the emergence of more adaptive and high-quality learning innovations.

6. Conclusion

The use of AI by teachers in mathematics learning has a highly positive impact on improving the quality of both learning processes and learning outcomes. The success of AI integration is strongly influenced by teachers' readiness to master technology through continuous training, enabling AI to function not only as a technical tool but also as a cognitive partner in designing innovative, adaptive, and student-centered learning. The use of AI enables more engaging, contextually relevant presentation of learning materials, reduces preparation time, supports automated assessment, and fosters an interactive, enjoyable learning environment. For students, this technology enhances motivation, conceptual understanding, and critical thinking skills while simultaneously reducing mathematics anxiety. With proper management and a strong pedagogical foundation, AI serves as a catalyst for transforming mathematics education toward more effective, creative learning that aligns with the demands of 21st-century competencies.

This systematic literature review demonstrates that the effective integration of AI in mathematics learning has important pedagogical and professional implications, particularly in strengthening adaptive, student-centered instruction while positioning teachers as reflective facilitators and learning designers rather than mere technology users. Continuous professional development, collaborative learning

communities, and sustained technological literacy emerge as essential conditions for ensuring that AI functions as a cognitive partner that enhances pedagogical decision-making and learning quality. Nevertheless, this study is limited by its reliance on secondary data from a specific publication period (2023–2025) and selected databases, which may restrict the generalizability of findings and overlook emerging practices or contextual variations across educational levels and regions. Therefore, future research is recommended to employ empirical and mixed-method approaches, including classroom-based experiments and longitudinal studies, to examine the long-term impact of AI integration on teachers' professional identity and students' mathematical competencies, as well as to explore ethical, regulatory, and equity-related dimensions of AI use in diverse educational contexts.

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