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AI IN MATHEMATICS TEACHER EDUCATION: TRENDS, CHALLENGES, AND OPPORTUNITIES

Abstract. Artificial intelligence (AI) is significantly reshaping mathematics teacher education by introducing innovative tools that enhance instructional design, promote personalization, and increase student engagement. This integrative review synthesizes recent research to identify key trends, opportunities, and challenges associated with AI integration in mathematics teacher education. Findings indicate a growing but inconsistent adoption among educators, highlighting the potential of conversational tools such as ChatGPT and adaptive learning systems to support personalized and inclusive instruction. AI-driven responsive teaching simulations, innovative task design, and advanced assessment practices further illustrate opportunities for enhancing preservice teachers' adaptive, student-centered teaching competencies. Beyond efficiency gains, AI tools also foster teacher agency and reflective practice in the design of adaptive and equitable mathematics instruction. Nevertheless, considerable challenges persist, including widespread teacher AI literacy gaps, ethical concerns surrounding data privacy, algorithmic bias, and transparency, as well as pedagogical risks related to automation and superficial learning. Additionally, persistent usability and design limitations complicate effective AI implementation. The review underscores the importance of developing targeted professional development frameworks, promoting theory-driven research, and establishing comprehensive policy guidelines. Recommendations emphasize embedding critical reflection and AI literacy within teacher training, advancing human–AI collaborative frameworks, and ensuring clear ethical standards. This synthesis provides educators, policymakers, and researchers with a robust, evidence-based foundation to effectively leverage AI's transformative potential while safeguarding educational integrity in mathematics teacher education.

Keywords: artificial intelligence (AI); mathematics teacher education; adaptive learning; conversational agents; ethical considerations.

1. INTRODUCTION

Artificial intelligence (AI) is rapidly transforming educational systems worldwide, introducing innovative tools and methodologies that significantly influence teaching practices, curriculum design, and teacher education. In mathematics education specifically, AI technologies offer significant potential to enhance instructional effectiveness through personalized learning pathways, adaptive feedback, and responsive teaching simulations [1], [2]. AI-driven tools, such as conversational agents like ChatGPT, intelligent tutoring systems, and AI-supported task-design platforms, have gained recognition for their ability to improve student engagement and comprehension of complex mathematical concepts [3], [4].

Despite this promising outlook, the integration of AI within mathematics teacher education remains inconsistent and insufficiently theorized. Current research highlights both strong interest and notable challenges among teachers and preservice educators. Common issues include limited familiarity with AI tools, inconsistent technological pedagogical content knowledge (TPACK), and critical ethical concerns related to bias, transparency, and data privacy [5]-[7]. Furthermore, existing literature underscores significant gaps in professional development frameworks needed to empower teachers to critically assess and effectively adapt AI-generated instructional materials to diverse learner needs [8], [9].

These trends highlight the necessity for a comprehensive and systematic examination of AI integration within mathematics teacher education. A thorough review of existing research can identify emerging practices, clarify persistent challenges, and uncover strategic

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opportunities to advance pedagogical and policy approaches. By synthesizing findings from diverse contexts, including adaptive learning systems in higher education [10] and AI-supported responsive teaching chatbots [11], this integrative review aims to establish an evidence-based foundation for reconceptualizing mathematics teacher education within an AI-enhanced learning environment.

The purpose of this review, therefore, is to systematically analyze the key trends, opportunities, and challenges associated with integrating AI into mathematics teacher education. Specifically, it addresses the following research questions:

1. What are the emerging trends in the use of AI technologies in mathematics teacher education?
2. What opportunities does AI present for enhancing mathematics teacher education and instructional practice?
3. What challenges and ethical considerations must be addressed to ensure responsible and effective AI integration?

By engaging these questions, this review aims to inform teacher educators, policymakers, and researchers seeking to develop responsive, equitable, and pedagogically sound approaches to preparing mathematics teachers for an increasingly AI-integrated educational future.

Building on this rationale, it is evident that research on the integration of AI into mathematics teacher education and professional learning remains fragmented and conceptually underdeveloped. Most existing studies emphasize student learning outcomes or general AI-supported instruction, offering limited insight into how AI transforms mathematics teacher education and pedagogical reasoning. To address this gap, the present integrative review synthesizes contemporary literature to identify current trends, challenges, and opportunities, and to clarify how AI technologies, pedagogical models, and policy initiatives collectively shape the evolving landscape of mathematics teacher education.

2. METHODOLOGY

This study adopted an integrative literature review approach to investigate how artificial intelligence (AI) is being incorporated into mathematics teacher education. This method aims to synthesize diverse forms of evidence, including empirical studies, conceptual analyses, and policy documents, to identify emerging trends, challenges, and opportunities relevant to teacher education.

The review was guided by the principles of methodological transparency and comprehensiveness, focusing on the identification of recurring ideas, pedagogical innovations, and theoretical contributions across multiple sources of research.

2.1 Search Strategy

A comprehensive literature search was conducted using Google Scholar, chosen for its extensive coverage of interdisciplinary research in education, technology, and teacher development. The search focused on studies published between January 2020 and January 2025, employing combinations of the following keywords: artificial intelligence, AI, chatbot, machine learning, mathematics education, and teacher education.

Priority was given to peer-reviewed journal articles and book chapters written in English that addressed AI applications, pedagogical frameworks, or theoretical models within the context of mathematics teacher education and professional learning.

2.2 Selection and Analysis

The initial pool of retrieved studies was screened for relevance to the review's focus. Publications dealing exclusively with student learning, general educational technology without AI components, or applications outside mathematics teacher education were excluded.

The remaining studies were analyzed through an iterative reading and coding process. For each included work, information was extracted regarding the educational context and level, the type of AI technology employed, the pedagogical purpose of its use, the underlying theoretical framework, and the reported outcomes or challenges. A thematic synthesis was then applied to identify cross-cutting ideas and conceptual linkages across the reviewed literature.

2.3 Analytical Framework

Rather than quantifying studies or reporting screening counts, the analysis emphasized qualitative integration, bringing together insights from different research traditions to reveal broader patterns and implications for both practice and policy. This interpretive approach enabled the identification of significant directions for future research and the formulation of evidence-informed recommendations for mathematics teacher education in the era of AI.

This methodological framework ensures analytical coherence, depth, and transparency, aligning with the study's exploratory and integrative objectives. It provides a strong foundation for understanding how AI technologies are reshaping the professional learning landscape of mathematics educators.

3. EMERGING TRENDS IN AI INTEGRATION

3.1 Growing but Uneven Adoption

Artificial intelligence has become an increasingly important aspect of mathematics teacher education; however, its integration remains inconsistent and variable across different educational contexts. F. Egara & M. Mosimege (2024) note a rising interest in AI among secondary mathematics teachers, yet only 17% actively incorporate AI tools into their teaching practices [1]. Studies involving preservice teachers similarly report widespread unfamiliarity and limited practical experience in employing AI technologies for lesson design and classroom instruction [12], [13].

Nevertheless, teachers who adopt AI technologies report meaningful benefits, including enhanced teaching effectiveness, increased student engagement, and improved understanding of complex mathematical concepts [1], [3]. F. Karataş, B. Eriçok & L. Tanrikulu (2025) illustrate how teachers utilize generative AI to dynamically adapt curricula, removing irrelevant content, extending lessons, and revising materials to align with student interests and needs [8]. These adaptations signify a move toward responsive, data-driven, and student-centered instructional planning. Furthermore, national-level initiatives reinforce these trends. For instance, C. Zhou (2023) highlights China's systematic approach to implementing AI-based personalized learning platforms within higher education mathematics curricula, demonstrating broader global efforts toward institutional investment in AI-enhanced education [10].

3.2 ChatGPT and Conversational Tools

Conversational AI, exemplified by tools such as ChatGPT, is emerging as a significant trend within mathematics teacher education. Y. Wardat, M. A. Tashtoush, R. AlAli & A. M. Jarrah (2023) document considerable enthusiasm among educators and students regarding ChatGPT's capacity to offer accessible and responsive instructional support [3]. Such tools

provide instant explanations and scaffolding, significantly extending the instructional reach beyond traditional classroom settings.

M. A. Kuhail, N. Alturki, S. Alramlawi & K. Alhejori (2023) systematically review 36 studies on educational chatbots, identifying diverse roles such as teaching agents, peer agents, and teachable agents [14]. These conversational tools effectively emulate human tutoring interactions in scalable and cost-effective manners, emphasizing personalized instruction, scaffolding, and adaptive learning.

Moreover, innovative uses in teacher education are increasingly evident. Y. Son, S. Yeo & D. Lee (2024) demonstrate AI chatbots' ability to simulate responsive teaching environments, allowing preservice teachers to practice adaptive questioning strategies safely and effectively [15]. N. Buchholtz & J. Huget (2024) further illustrate ChatGPT's utility as a reflective tool, prompting preservice teachers to critically evaluate and enhance their lesson planning practices [16]. However, they caution against potential pitfalls such as adopting overly generic scripts.

3.3 Research Bibliometrics and Topic Mapping

Bibliometric and integrative reviews further illuminate emerging trends in AI integration within mathematics education research. G.-J. Hwang and Y.-F. Tu (2021) observed a steady increase in publications since 2010, particularly in studies on intelligent tutoring systems, predictive modeling, and adaptive learning environments [17]. This growth reflects the global shift toward individualized, AI-supported instruction and the growing interest in learning analytics as a tool for improving teaching efficiency and responsiveness.

Building on this trajectory, X. Chen, H. Xie, D. Zou, and G.-J. Hwang (2020) identified enduring theoretical and methodological gaps across highly cited Artificial Intelligence in Education (AIEd) studies [18]. Their analysis revealed a continued dependence on rule-based and Natural Language Processing (NLP) approaches, while more advanced deep-learning and neural-network techniques remain underrepresented. Equally important, their review underscored the limited incorporation of pedagogical and psychological theory, highlighting the need for models that link technological sophistication with teacher-education objectives.

C. Büscher (2020) extended this discussion by demonstrating how AI methodologies can be applied not only to support instruction but also to study mathematics education itself [19]. Automated analyses of teacher interactions and classroom discourse now enable fine-grained exploration of questioning strategies, feedback patterns, and instructional design decisions at scales previously unattainable. These methodological advances point to the potential of AI to generate rich, data-driven insights for both research and teacher education.

Collectively, these bibliometric investigations reveal a field that is expanding rapidly yet remains theoretically fragmented. The overall state of the art reflects increasing interdisciplinarity, bridging education, computer science, and cognitive psychology, but still lacks cohesive frameworks that connect AI’s technical capacities with pedagogical reasoning in teacher education. Future research should therefore prioritize theoretical synthesis, mixed-method designs, and longitudinal analyses that capture how AI technologies influence teacher learning and professional identity over time.

3.4 Research Growth Trends

Publication trends over the past five years reflect a rapidly growing academic interest in AI applications within mathematics education. A Google Scholar search for "artificial intelligence" AND "mathematics education" revealed a significant increase from 1,910 publications in 2020 to 10,400 publications in 2024, as illustrated in Fig. 1. This sharp growth underscores intensifying global research interest in AI’s transformative potential in

mathematics education, highlighting the critical relevance and timeliness of this integrative review.

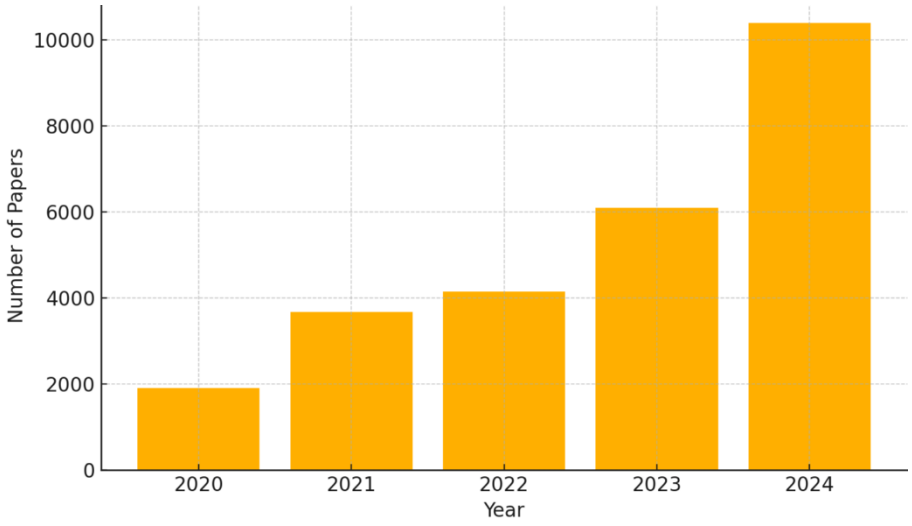

Figure 1. Number of publications on "artificial intelligence" and "mathematics education" indexed in Google Scholar, 2020–2024.

This upward trend not only reflects increasing technological adoption but also signals heightened recognition among educators, researchers, and policymakers of the opportunities and challenges associated with AI integration in mathematics education.

3.5 Focused Trends in Mathematics Teacher Education

A narrower focus on mathematics teacher education specifically reveals parallel yet specialized growth trends. A targeted Google Scholar search for "artificial intelligence" AND "mathematics teacher education" indicates a rise from 124 publications in 2020 to 456 publications in 2024, representing more than a threefold increase over five years (Fig. 2). This trajectory emphasizes the expanding scholarly attention directed toward AI integration specifically within mathematics teacher education.

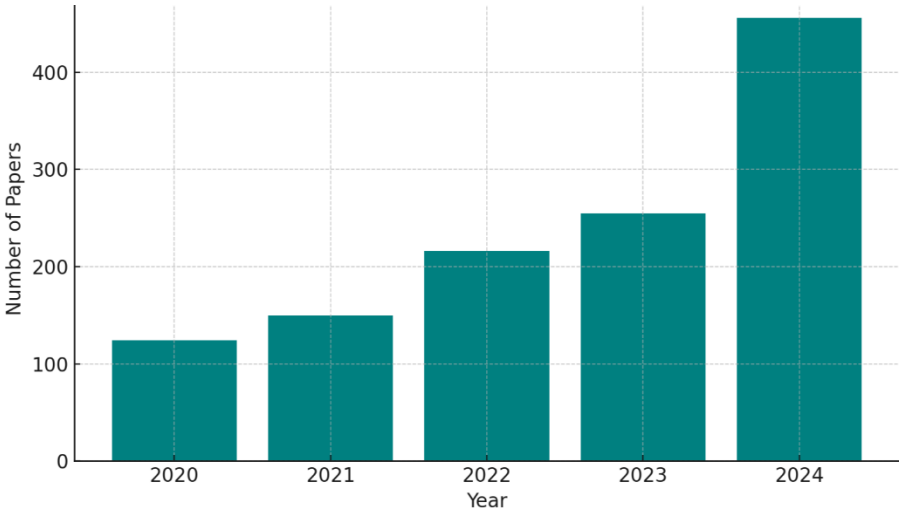

Figure 2. Number of publications on "artificial intelligence" and "mathematics teacher education" indexed in Google Scholar, 2020–2024.

Collectively, these broader and focused publication trends demonstrate accelerated research interest in AI's application within mathematics education broadly and mathematics teacher education specifically. Such growth underscores the urgency and importance of systematically reviewing current practices, identifying emerging opportunities, and addressing persistent challenges to effectively prepare mathematics educators for future AI-integrated teaching environments.

4. OPPORTUNITIES FOR MATHEMATICS TEACHER EDUCATION

Given the emerging trends and growing interest identified in the previous sections, it is crucial to systematically examine the potential benefits AI offers for mathematics teacher education. A clear understanding of these opportunities can guide educators, policymakers, and researchers in leveraging AI effectively to enhance teacher education and instructional quality. Table 1 categorizes key literature according to thematic areas central to AI integration in mathematics teacher education.

Table 1

Key References by Theme Informing AI Opportunities in Mathematics Teacher Education

Theme	Representative References
Personalization & Inclusive Learning	[2], [3], [10], [20], [21]
AI Chatbots / Conversational Tools	[3], [11], [15], [14], [16]
Responsive Teaching Simulations	[11], [15], [24]
Task Design / Assessment Innovation	[25], [26]
Teacher Knowledge / AI Literacy	[8], [9], [13], [32]
Ethical / Policy Issues	[6], [7], [28], [34]
Research Mapping / Trends	[17], [18], [19]

This thematic organization ensures a comprehensive exploration of AI integration opportunities, challenges, and future recommendations for mathematics teacher education.

4.1 Personalization and Inclusive Learning

AI creates significant opportunities for personalized and inclusive learning within mathematics education by enabling tailored instructional experiences and adaptive learning paths. O. O. Adeleye, C. A. Eden & I. S. Adeniyi (2024) emphasize AI's ability to provide adaptive educational experiences, enabling more effective responses to diverse student needs and promoting equity in classroom environments [2]. S. Orhani (2024) similarly identifies how AI-driven personalization of mathematics tasks can improve student performance, motivation, and engagement by aligning tasks with individual learning styles and needs [20].

O. B. Joseph & N. C. Uzondu (2024) highlight the inclusive potential of adaptive AI tools, noting their capability to identify and address learning gaps in real-time [21]. Y. Wardat, M. A. Tashtoush, R. AlAli & A. M. Jarrah (2023) further illustrate the role of ChatGPT as a personalized learning assistant, providing immediate feedback and scaffolding, thereby supporting independent problem-solving and self-directed learning [3]. Collectively, these insights position AI as a key partner in achieving large-scale, equitable, personalized instruction.

4.2 STEAM and Computational Thinking

AI integration facilitates interdisciplinary, project-based learning models essential for cultivating computational thinking skills. X. Huang & C. Qiao (2024) demonstrate that embedding AI within high school STEAM curricula fosters inquiry-based approaches, enhancing problem-solving, critical thinking, and computational abilities [22]. Teacher education programs, consequently, must equip preservice teachers to design and implement AI-enhanced interdisciplinary projects that promote creativity and the authentic application of mathematical concepts.

A. Astin Dhayananth & K. Subash (2025) further assert that mathematical literacy necessitates integrating technology, equity-focused practices, and interdisciplinary approaches [23]. AI technologies enable educators to create tasks involving real-world data, model intricate phenomena, and link mathematical reasoning with broader STEAM contexts, thus significantly enriching mathematics education.

4.3 Responsive Teaching Simulations

AI-based simulations offer promising avenues for teacher education, enabling preservice teachers to practice responsive teaching strategies in low-risk, structured environments. D. Lee & S. Yeo (2022) develop an AI-driven chatbot to simulate realistic, open-ended classroom interactions, helping preservice teachers refine adaptive questioning and real-time feedback skills crucial for equitable mathematics instruction [11].

Y. Son, S. Yeo & D. Lee (2024) corroborate these findings, illustrating how AI chatbots can effectively create controlled responsive teaching scenarios [15]. Additionally, T. J. Gurl, M. P. Markinson, & A. F. Artzt (2025) highlight ChatGPT's role as a lesson-planning aid, prompting reflective practice and fostering student-centered, responsive pedagogical strategies [24].

4.4 Task Design and Assessment Innovation

AI also presents opportunities to revolutionize task design and assessment practices within mathematics teacher education. F. Peters & S. Schorcht (2024) illustrate how teachers can leverage GPT agent networks to prototype and adapt mathematics tasks rapidly, thus enhancing instructional flexibility and differentiation [25]. Their research emphasizes iterative human oversight to maintain conceptual integrity and pedagogical coherence, highlighting critical skills for teacher education programs to cultivate.

A. Hodge-Zickerman & C. S. York (2024) specifically address assessment innovation, proposing that AI tools such as ChatGPT can facilitate the creation of assessments focused on conceptual understanding, critical thinking, and mathematical reasoning [26]. They advocate for integrating AI into assessment practices to enrich learning rather than viewing AI as merely posing risks to assessment integrity.

4.5 AI as a Thinking Partner

Beyond automating instructional tasks, AI can effectively serve as a thinking partner, promoting reflective and critical pedagogical practice among mathematics educators. M. Applebaum (2025) demonstrates how analyzing AI-driven problem-solving processes can model expert-level reasoning and expose errors for critical reflection [27]. This partnership positions AI as complementary to teacher expertise rather than a replacement.

Chatbots, according to N. Buchholtz & J. Huget (2024) and S. Bouffard (2024), further support preservice teachers in developing critical AI literacy [16], [9]. These tools help educators evaluate AI-generated materials for accuracy, developmental appropriateness, and

pedagogical value. Embracing such collaborations reinforces a vision of teacher education where AI integration is thoughtful, ethical, and supportive of professional growth.

4.6 Examples of AI Tools in Mathematics Teacher Education

To bridge the conceptual insights of this review with current practice, the following examples illustrate how AI systems are being employed in mathematics teacher education. The integration of artificial intelligence (AI) in mathematics teacher education is increasingly reflected in the growing use of intelligent systems that support pedagogical design, assessment, and professional learning. Among the key tools currently shaping the field are ChatGPT, Khanmigo, Century Tech, Squirrel AI, DreamBox, Google Socratic, Microsoft Copilot for Education, and NotebookLM.

ChatGPT and other large language models are widely used to assist teachers in lesson planning, generating explanations of mathematical concepts, and simulating classroom interactions for reflective practice. These applications enable preservice teachers to explore AI-mediated communication and feedback while developing strategies for responsible use. Khanmigo, an AI platform developed by Khan Academy, provides personalized instructional pathways and adaptive questioning aligned with mathematics curricula. It helps teacher candidates understand how algorithmic feedback can individualize instruction and enhance formative assessment.

Century Tech and Squirrel AI demonstrate how predictive analytics and real-time data can be leveraged to support differentiated instruction and formative assessment practices. These systems allow teachers to experiment with adaptive learning environments and analyze student performance data for evidence-based decision-making. Similarly, DreamBox Learning integrates adaptive algorithms to create dynamic mathematical tasks, enabling teacher educators to illustrate the relationship between automated personalization and pedagogical intent.

Google Socratic and Microsoft Copilot for Education exemplify the use of AI assistants to enhance content creation, resource retrieval, and formative assessment. These tools illustrate the potential of generative AI to facilitate inquiry, automate feedback, and support lesson preparation, while emphasizing the need for ethical awareness and critical evaluation of machine-generated outputs. NotebookLM, a more recent innovation, offers teachers and researchers an AI-powered workspace for synthesizing readings, generating summaries, and connecting insights across multiple sources. Its use in teacher education highlights how AI can augment academic inquiry, lesson analysis, and professional reflection.

Collectively, these systems illustrate how AI technologies are transforming the professional preparation of mathematics teachers. Their applications underscore the importance of developing AI literacy, ethical competence, and pedagogical adaptability as essential dimensions of teacher education in the era of intelligent technologies.

5. CHALLENGES AND CONCERNS

5.1 Teacher Knowledge and AI Literacy Gaps

A central challenge in integrating AI into mathematics teacher education is the limited teacher knowledge and insufficient AI literacy. Numerous studies indicate that both in-service and preservice teachers frequently lack familiarity with AI tools and express low confidence in their capacity to critically evaluate and adapt AI-generated instructional materials [1], [12], [13]. F. Karataş, B. Eriçok & L. Tanrikulu (2025) highlight the ad-hoc and unsystematic nature

of teachers' use of AI for real-time curricular adaptations, underscoring the absence of coherent training frameworks [8].

S. Bouffard (2024) emphasizes that professional development must extend beyond mere tool-specific training and focus on fostering foundational AI understanding [9]. By demystifying AI processes and predictive mechanisms, teacher education programs can better equip educators to critically appraise AI-generated outputs, mitigating the risk of overdependence and ensuring the thoughtful integration of AI within instructional strategies.

5.2 Ethical Issues (Privacy, Bias, Transparency)

The incorporation of AI into mathematics teacher education presents significant ethical concerns related to data privacy, algorithmic bias, and transparency. M. M. Awang, N. M. Yusop & M. Danaee (2025) raise critical issues regarding the handling of student data and the potential for AI systems to perpetuate and amplify existing social biases, thus exacerbating inequities within classroom settings [6]. Similarly, M. Giannakos, Z. Papamitsiou, K. Sharma, I. O. Pappas & D. G. Sampson (2024) caution against prematurely adopting generative AI without robust policy frameworks, highlighting risks such as algorithmic bias, lack of transparency, and the undermining of human-centered pedagogical approaches [7].

M. ElAzab & M. Louis (2023) further advocate for proactive, deliberate policy measures to address these ethical concerns [28]. Ensuring ethical governance and educator oversight becomes paramount as AI increasingly shapes instructional decisions, thereby safeguarding equitable educational practices and protecting students' rights and privacy.

5.3 Risks of Automation and Superficial Learning

Despite the promising efficiencies and personalized instructional support offered by AI, reliance on automation poses substantial risks to the depth and quality of learning. R. Davis (2024) observes that preservice teachers frequently struggle to shift from traditional, authoritative teaching to reflective, responsive methods, a transition potentially hindered by AI tools that deliver rapid responses lacking pedagogical depth [29].

Additionally, T. Pörn, T. Marklund & J. Westerlund (2024) caution that excessive reliance on AI interactions could shift students' focus away from critical mathematical reasoning toward superficial interactions with technology, undermining genuine conceptual understanding [30]. R. Zviel-Girshin (2024) reinforces these concerns within programming education contexts, noting that while AI can efficiently handle routine tasks and offer immediate feedback, it may inadvertently foster superficial learning if educators do not strategically scaffold deeper problem-solving and critical thinking skills [31].

5.4 Usability and Design Limitations

AI tools designed for educational contexts frequently encounter usability and design challenges that diminish their effectiveness in teacher education. D. Lee & S. Yeo (2022) highlight significant difficulties in developing educational chatbots capable of realistically addressing diverse student misconceptions [11]. Their iterative design experiences revealed that overly scripted or narrowly focused chatbots often fail to simulate authentic classroom dynamics, thus limiting their utility in training preservice teachers in responsive pedagogies.

Similarly, M. A. Kuhail, N. Alturki, S. Alramlawi & K. Alhejori (2023) identify persistent design limitations in educational chatbots, including insufficient training data, rigid conversational flows, and inadequate application of usability principles [14]. Their systematic review underscores the necessity for improved design guidelines, rigorous user experience

testing, and empirical validation to ensure AI tools genuinely support teacher learning and instructional effectiveness.

X. Chen, H. Xie, D. Zou & G.-J. Hwang (2020) further highlight a significant disconnect between highly cited AI in Education (AIEd) studies and robust educational theories, raising concerns about superficial adoption of AI tools without adequate pedagogical alignment [18]. These insights emphasize the critical importance of enhancing preservice teacher training to build robust critical AI literacy, enabling educators to evaluate, customize, and ethically integrate AI technologies within their professional practice.

6. DISCUSSION

This review set out to explore three central questions regarding the integration of artificial intelligence (AI) in mathematics teacher education. The synthesis provided here consolidates the key findings and explicitly addresses these questions to highlight implications for future practice and research.

6.1 Emerging Trends in AI Technologies in Mathematics Teacher Education

The findings reveal a clear yet uneven trend toward the adoption of AI technologies within mathematics teacher education, marked by growing interest alongside inconsistent implementation. The most widely used tools such as ChatGPT, intelligent tutoring systems, and adaptive learning platforms, are increasingly utilized. Educators have demonstrated innovative applications of AI for curriculum adaptation and personalized instructional planning [8], [12]. Nevertheless, widespread adoption remains limited due to educators' inconsistent familiarity, inadequate training, and gaps in foundational AI literacy [1], [13]. Bibliometric analyses underscore a notable focus on intelligent tutoring systems, predictive models, and adaptive technologies [17], coupled with rising interest in dialog-based tools like chatbots designed to facilitate responsive teaching practices [14], [15]. Additionally, significant theoretical and methodological gaps persist, with advanced AI techniques underutilized and insufficiently integrated within pedagogical frameworks [18].

6.2 Opportunities for Enhancing Mathematics Teacher Education and Instruction

AI presents considerable opportunities to enrich mathematics teacher education through personalization, inclusive learning, and differentiated instruction. Research emphasizes AI's capability to create customized learning pathways, deliver instant feedback, and promote equitable educational outcomes [2], [3], [20]. AI-powered simulations and conversational agents, such as chatbots, provide preservice teachers with realistic, low-stakes environments to practice adaptive questioning and responsive pedagogical strategies [11], [24]. Moreover, AI supports innovative approaches in task design and assessment, enabling rapid prototyping of instructional activities that foster critical thinking, conceptual understanding, and effective pedagogical alignment [25], [26]. Additionally, AI functions as a valuable reflective partner, promoting critical examination and thoughtful pedagogical decision-making among educators [16], [27].

6.3 Challenges and Ethical Considerations for Effective AI Integration

Despite these promising opportunities, substantial challenges and ethical concerns must be thoughtfully addressed to ensure responsible and effective integration of AI. Foremost among these challenges are the widespread gaps in teacher knowledge and AI literacy, which

can lead to superficial or inappropriate application of AI tools [8], [9]. Ethical considerations related to data privacy, algorithmic bias, and transparency further complicate the landscape, demanding careful policy frameworks and oversight mechanisms to safeguard student rights and equity [6], [7], [28].

Furthermore, pedagogical risks associated with over-reliance on automation pose significant threats to deep conceptual understanding and critical reasoning skills. Research cautions against a shift toward superficial engagement with AI rather than meaningful mathematical reasoning [29], [30], [31]. Additionally, persistent usability and design limitations in educational AI tools, including inadequate simulation of authentic classroom interactions, underscore the importance of iterative, theory-informed design processes ([11], [14]).

6.4 Limitations of the Review

Despite rigorous methodology, this review has several limitations. Firstly, the reliance on publications indexed primarily in databases such as Google Scholar may have omitted relevant grey literature, unpublished studies, or reports published in non-English languages, potentially limiting the comprehensiveness of findings. Secondly, the rapidly evolving nature of AI technology means that certain recent innovations or developments may not be fully represented. Additionally, this review focuses primarily on teacher education perspectives, providing limited direct insight into student experiences or broader educational outcomes. Future reviews should aim to incorporate wider linguistic and geographical scopes, diverse data sources, and consider a broader range of stakeholders to further enrich the understanding of AI integration in mathematics teacher education.

In summary, these findings emphasize the urgent need for targeted professional development, comprehensive ethical frameworks, and robust research initiatives to enhance the effective integration of AI in mathematics teacher education. By fostering critical AI literacy and promoting reflective, student-centered approaches, teacher education programs can leverage AI's transformative potential while upholding their foundational humanistic and equitable educational objectives.

7. FUTURE DIRECTIONS AND RECOMMENDATIONS

7.1 Professional Development and Training Frameworks

To fully harness the transformative potential of AI in mathematics teacher education, targeted, systematic professional development programs are essential. Effective training should extend beyond basic familiarity with AI tools and emphasize a foundational understanding of AI processes and limitations [9]. Such training would empower teachers to critically evaluate AI-generated outputs and minimize the risk of unreflective dependence on automated tools. T. Trust, R. W. Maloy & N. Hikmatullah (2024) further propose integrating AI into established frameworks such as Teacher Educator Technology Competencies (TETCs), focusing on ethical awareness, cultural responsiveness, and strategies for supporting diverse learners [32].

Professional development initiatives should also incorporate critical reflection practices, guiding educators in assessing AI-generated resources for their age appropriateness, conceptual clarity, and pedagogical alignment [8], [24]. Scenario-based training with AI-driven chatbots, as demonstrated by Y. Son, S. Yeo & D. Lee (2024) and D. Lee & S. Yeo (2022), illustrates the practical benefits of providing preservice teachers with authentic, safe environments to refine responsive teaching techniques and adaptive feedback [15], [11].

7.2 Research Needs and Theory Integration

Addressing existing research gaps is critical for advancing AI integration within mathematics teacher education. X. Chen, H. Xie, D. Zou & G.-J. Hwang (2020) underscore the necessity of grounding AI applications in robust pedagogical theories, noting significant theoretical deficiencies in current AI education research [18]. G.-J. Hwang and Y.-F. Tu (2021) advocate for broader, multidisciplinary research encompassing cognitive, affective, and collaborative dimensions of learning across various mathematical domains [17].

Future research should prioritize discipline-specific explorations, particularly in the areas of AI-supported task design [25] and innovative assessment methods [26]. Aligning AI tools with well-established educational theories, such as cognitive development models [33] and computational thinking frameworks [22], will further ensure meaningful, student-centered learning experiences facilitated by AI.

7.3 Pedagogical Alignment

Thoughtful pedagogical alignment is vital to ensure AI tools enhance rather than replace teachers' instructional judgment. P. Mishra & M. K. Heath (2024) highlight the importance of critically assessing AI technologies to understand their underlying values, intended beneficiaries, and impacts on instructional priorities [34]. Promoting human–AI collaborative frameworks [35] positions AI as a supportive partner that complements educators' expertise rather than diminishing human-centered teaching practices.

Teacher education programs must actively support preservice teachers in evaluating and customizing AI-generated materials to meet diverse student needs effectively. Encouraging reflective and responsive instructional design practices ensures that AI integration aligns with equity-focused, student-centered teaching approaches [16], [27].

7.4 Policy Safeguards

Effective integration of AI in mathematics teacher education necessitates proactive policy frameworks addressing ethical, legal, and infrastructural considerations. Critical concerns such as data privacy, algorithmic bias, and transparency require clear policy guidelines to safeguard student rights and promote equitable access [6], [7].

M. ElAzab & M. Louis (2023) emphasize the importance of maintaining educator oversight and ethical governance as AI increasingly influences instructional decisions [28]. Comprehensive policy measures must ensure AI tools are rigorously evaluated for bias, usability, and pedagogical soundness, equipping teachers with the necessary training and resources for responsible implementation.

Given the rapid expansion of research publications on AI in mathematics education and mathematics teacher education, concerted efforts are urgently needed to establish professional development frameworks, ethical policy standards, and robust research agendas. These measures will ensure ethical, effective, and pedagogically grounded AI integration, fostering innovative educational environments that maintain equity, inclusivity, and pedagogical integrity in mathematics teacher education.

7.5 Long-Term Impact and Sustainability

As AI continues to gain prominence in mathematics teacher education, understanding its long-term implications becomes essential. Sustained integration of AI technologies may fundamentally alter educators' professional roles, shifting their responsibilities toward overseeing personalized, AI-driven instruction, and increasing demands for critical reflection and technological proficiency. It is vital to anticipate potential changes in teacher professional

identities and to ensure that AI tools enhance, rather than diminish, the human dimensions of teaching. Sustainability also depends on continuously updating educators' knowledge bases and adapting professional development to align with technological advancements. Future research should therefore explore longitudinal impacts on educator roles, student learning outcomes, and educational equity to inform policies and practices that maintain ethical, equitable, and pedagogically sound AI integration over time.

8. CONCLUSION

This integrative review has examined emerging trends, opportunities, and challenges in the incorporation of artificial intelligence (AI) into mathematics teacher education. The reviewed literature indicates a growing international awareness of AI's potential to enhance teacher education through adaptive learning environments, intelligent tutoring systems, and data-driven pedagogical support. Beyond technological efficiency, recent developments indicate an increasing movement toward interdisciplinary collaboration and theory-informed design, signaling a maturing field that seeks to align AI innovation with pedagogical reasoning and professional identity formation.

At the same time, the analysis underscores persistent challenges related to limited AI literacy, ethical governance, and the absence of coherent theoretical frameworks to guide implementation. Effective integration of AI in mathematics teacher education therefore requires not only technological competence but also pedagogical depth, ethical awareness, and critical reflection on practice.

To guide future research and development, several practical recommendations are proposed. Teacher education programs should prioritize structured professional development that fosters AI literacy and integrates ethical and pedagogical perspectives. International policy frameworks, such as UNESCO's AI Competency Framework for Educators [36] and the European Union's Artificial Intelligence Act [37], ought to be embedded within curricula to ensure coherence with emerging global standards. In parallel, clear evaluation criteria should be established to assess AI-supported tools in terms of bias, transparency, and pedagogical usability.

Furthermore, promoting models of human – AI collaboration that emphasize teacher agency, professional judgment, and equitable learning design will be essential for fostering responsible innovation. Continued longitudinal research is also needed to investigate how AI integration influences teachers' professional identity, instructional quality, and student learning outcomes over time.

By embedding these recommendations within institutional, professional, and policy frameworks, mathematics teacher education can advance toward a responsible, evidence-informed adoption of AI, one that embraces innovation while preserving the reflective, humanistic, and equity-oriented foundations of the teaching profession.

REFERENCES (TRANSLATED AND TRANSLITERTED)

[1] F. Egara and M. Mosimege, "AI in secondary mathematics teaching: A survey of teachers' awareness and integration," *African Journal of Mathematics Education*, vol. 15, no. 2, pp. 33–51, 2024. https://doi.org/10.3390/educsci14070742. (in English)

[2] O. O. Adeleye, C. A. Eden, and I. S. Adeniyi, "Innovative teaching methodologies in the era of artificial intelligence: A review of inclusive educational practices," *World Journal of Advanced Engineering Technology and Sciences,* vol. 11, no. 2, pp. 069–079, 2024. https://doi.org/10.30574/wjaets.2024.11.2.0091. (in English)

[3] Y. Wardat, M. A. Tashtoush, R. AlAli, and A. M. Jarrah, "ChatGPT: A revolutionary tool for teaching and learning mathematics," *EURASIA Journal of Mathematics, Science and Technology*

Education, vol. 19, no. 7, Art. no. em2286, 2023. https://doi.org/10.29333/ejmste/13272. (in English)

[4] Z. Xing, H. Guo, and C. C. Lam, "ALTER-Math: An AI-powered teachable agent supporting learning-by-teaching in mathematics," *Computers & Education*, vol. 197, Art. no. 104742, 2025. https://doi.org/10.1016/j.compedu.2023.104742. (in English)

[5] X. Li, "Barriers to AI integration in primary mathematics education: A TPACK perspective," *International Journal of STEM Education Research*, vol. 6, no. 1, pp. 18–37, 2025. https://doi.org/10.1016/j.compedu.2022.104646. (in English)

[6] M. M. Awang, N. M. Yusop, and M. Danaee, "Ethical concerns in AI adoption in education: Data privacy, bias, and transparency," *Journal of Educational Technology Ethics*, vol. 14, no. 1, pp. 44–62, 2025. https://doi.org/10.29333/iejme/16006. (in English)

[7] M. Giannakos, Z. Papamitsiou, K. Sharma, I. O. Pappas, and D. G. Sampson, "The promise and challenges of generative AI in education," *Behaviour & Information Technology*, early access, 2024. https://doi.org/10.1080/0144929X.2024.2394886. (in English)

[8] F. Karataş, B. Eriçok, and L. Tanrikulu, "Reshaping curriculum adaptation in the age of artificial intelligence: Mapping teachers' AI-driven curriculum adaptation patterns," *British Educational Research Journal*, vol. 51, no. 1, pp. 154–180, 2025. https://doi.org/10.1002/berj.4068. (in English)

[9] S. Bouffard, "What educators need to know about AI, Q&A With Justin Reich," *The Learning Professional*, vol. 45, no. 2, pp. 36–39, 2024. (in English)

[10] C. Zhou, "Integration of modern technologies in higher education on the example of artificial intelligence use," *Education and Information Technologies*, vol. 28, pp. 3893–3910, 2023. https://doi.org/10.1007/s10639-022-11309-9. (in English)

[11] D. Lee and S. Yeo, "Developing an AI-based chatbot for practicing responsive teaching in mathematics," *Computers & Education*, vol. 191, Art. no. 104646, 2022. https://doi.org/10.1016/j.compedu.2022.104646. (in English)

[12] A. Sawyer, "Preservice teachers' use of AI for curriculum planning: Opportunities and challenges," *Teacher Education Quarterly*, vol. 51, no. 1, pp. 59–82, 2024. https://doi.org/10.62365/2576-0955.1106. (in English)

[13] R. J. B. Magat and E. M. Sangalang, "Teachers' familiarity, perceptions, and training needs on the use of ChatGPT in mathematics instruction," *International Journal of Education in Mathematics, Science, and Technology*, vol. 12, no. 4, pp. 1471–1487, 2024. https://doi.org/10.46328/ijemst.4332. (in English)

[14] M. A. Kuhail, N. Alturki, S. Alramlawi, and K. Alhejori, "Interacting with educational chatbots: A systematic review," *Education and Information Technologies*, vol. 28, pp. 973–1018, 2023. https://doi.org/10.1007/s10639-022-11177-3. (in English)

[15] Y. Son, S. Yeo, and D. Lee, "Responsive teaching practice in preservice teacher education with AI chatbots," *Journal of Digital Learning in Teacher Education*, vol. 40, no. 1, pp. 22–35, 2024. https://doi.org/10.1016/j.tate.2024.104640. (in English)

[16] N. Buchholtz and J. Huget, "ChatGPT as a reflection tool to promote the lesson planning competencies of pre-service teachers," in *Proceedings of the 17th ERME Topic Conference MEDA4*, E. Faggiano, A. Clark-Wilson, M. Tabach, and H.-G. Weigand, Eds. University of Bari Aldo Moro, pp. 129–136, 2024. (in English)

[17] G.-J. Hwang and Y.-F. Tu, "Roles and research trends of artificial intelligence in mathematics education: A bibliometric mapping analysis and systematic review," *Mathematics*, vol. 9, no. 6, Art. no. 584, 2021. (in English)

[18] X. Chen, H. Xie, D. Zou, and G.-J. Hwang, "Application and theory gaps during the rise of Artificial Intelligence in Education," *Computers and Education: Artificial Intelligence*, vol. 1, Art. no. 100002, 2020. https://doi.org/10.1016/j.caeai.2020.100002. (in English)

[19] C. Büscher, "Scaling up qualitative mathematics education research through artificial intelligence methods," *For the Learning of Mathematics*, vol. 40, no. 2, pp. 2–7, 2020. (in English)

[20] S. Orhani, "Personalization of Math Tasks for each Student through AI," *Research Inventory: International Journal of Engineering and Science*, vol. 14, no. 3, pp. 18–28, 2024. (in English)

[21] O. B. Joseph and N. C. Uzondu, "Integrating AI and Machine Learning in STEM education: Challenges and opportunities," *Computer Science & IT Research Journal*, vol. 5, no. 8, pp. 1732–1750, 2024. (in English)

[22] X. Huang and C. Qiao, "Enhancing computational thinking skills through artificial intelligence education at a STEAM high school," *Science & Education*, vol. 33, pp. 383–403, 2024. https://doi.org/10.1007/s11191-022-00392-6. (in English)

[23] A. Astin Dhayananth and K. Subash, "Preparing for the future with mathematical literacy: An overview of emerging curriculum and instructional approaches," in *Contemporary Techniques in*

Math Education, S. Abbas, M. Sumathi, S. Riyasdeen, and A. Dinesh Kumar, Eds. TULSI Global Publishing House, pp. 17–24, 2025. (in English)

[24] T. J. Gurl, M. P. Markinson, and A. F. Artzt, "Using ChatGPT as a lesson planning assistant with preservice secondary mathematics teachers," *Digital Experiences in Mathematics Education*, vol. 11, pp. 114–139, 2025. https://doi.org/10.1007/s40751-024-00162-9. (in English)

[25] F. Peters and S. Schorcht, "AI-supported mathematical task design with a GPT agent network," in *Proceedings of the 17th ERME Topic Conference MEDA4*, E. Faggiano, A. Clark-Wilson, M. Tabach, and H.-G. Weigand, Eds. University of Bari Aldo Moro, pp. 327–334, 2024. (in English)

[26] A. Hodge-Zickerman and C. S. York, "Embracing ChatGPT in the evolving landscape of mathematics teacher education and assessment," in *Exploring New Horizons: Generative Artificial Intelligence and Teacher Education*, M. Searson, E. Langran, and J. Trumble, Eds. Association for the Advancement of Computing in Education, pp. 111–128, 2024. (in English)

[27] M. Applebaum, "Thinking with machines: How AI solves math puzzles and what educators can learn," *International Journal of Advanced Research in Science, Communication and Technology*, vol. 5, no. 13, pp. 355–363, 2025. https://doi.org/10.48175/IJARSCT-26055. (in English)

[28] M. ElAzab and M. Louis, "Will AI replace teachers? Policy and ethical reflections on AI adoption in education," *International Journal of Internet Education*, 2023. [Online]. Available: http://ijie.journals.ekb.eg (in English)

[29] R. Davis, "Korean in-service teachers' perceptions of implementing artificial intelligence (AI) education for teaching in schools and their AI teacher training programs," *International Journal of Information and Education Technology*, vol. 14, no. 2, pp. 214–219, 2024. https://doi.org/10.18178/ijiet.2024.14.2.2042. (in English)

[30] T. Pörn, T. Marklund, and J. Westerlund, "AI in mathematics classrooms: Focusing on skills or dialogue?," *Nordic Studies in Mathematics Education*, vol. 29, no. 1, pp. 21–38, 2024. https://doi.org/10.31129/LUMAT.12.3.2102. (in English)

[31] R. Zviel-Girshin, "The good and bad of AI tools in novice programming education," *Education Sciences*, vol. 14, no. 10, Art. no. 1089, 2024. https://doi.org/10.3390/educsci14101089. (in English)

[32] T. Trust, R. W. Maloy, and N. Hikmatullah, "Integrating AI in teacher education using the Teacher Educator Technology Competencies," in *Exploring New Horizons: Generative Artificial Intelligence and Teacher Education*, M. Searson, E. Langran, and J. Trumble, Eds. Association for the Advancement of Computing in Education, 2024, pp. 26–38. (in English)

[33] K. Sridhar and S. Balamurugan, "Cognitive growth and mathematical comprehension: A review of contemporary educational theories," in *Contemporary Techniques in Math Education*, S. Abbas, M. Sumathi, S. Riyasdeen, and A. Dinesh Kumar, Eds. TULSI Global Publishing House, 2025, pp. 40–52. (in English)

[34] P. Mishra and M. K. Heath, "The (Neil) Postman always rings twice: Five questions on AI and education," in *Exploring New Horizons: Generative Artificial Intelligence and Teacher Education*, M. Searson, E. Langran, and J. Trumble, Eds. Association for the Advancement of Computing in Education, 2024, pp. 14–25. (in English)

[35] J. Kim, "Leading teachers' perspective on teacher-AI collaboration in education," *Education and Information Technologies*, vol. 29, no. 7, pp. 8693–8724, 2024. https://doi.org/10.1007/s10639-023-12109-5. (in English)

[36] UNESCO, AI Competency Framework for Teachers. United Nations Educational, Scientific and Cultural Organization, Paris, France, 2023. [Online]. Available: https://ju.se/download/18.53389cd2193ed80e16f93737/1737107948692/UNESCO%20AI%20competency%20for%20teachers.pdf (in English)

[37] European Parliament and Council of the European Union, Regulation (EU) 2024/1689 of the European Parliament and of the Council on Artificial Intelligence and amending certain Union legislative acts (Artificial Intelligence Act). Official Journal of the European Union, L, Jul. 12, 2024. [Online]. Available: https://eur-lex.europa.eu/eli/reg/2024/1689/oj (in English)

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ШТУЧНИЙ ІНТЕЛЕКТ У ПІДГОТОВЦІ ВЧИТЕЛІВ МАТЕМАТИКИ: ТЕНДЕНЦІЇ, ВИКЛИКИ ТА МОЖЛИВОСТІ

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Анотація. Штучний інтелект (ШІ) суттєво змінює підготовку вчителів математики, запроваджуючи інноваційні інструменти, що покращують дизайн навчання, сприяють персоналізації та підвищують залученість учнів. Цей огляд поєднує різні підходи, узагальнює останні дослідження з метою визначення ключових тенденцій, можливостей та викликів, пов'язаних з інтеграцією ШІ у підготовку вчителів математики. Результати вказують на зростаюче, але нерівномірне впровадження серед освітян таких інструментів, як ChatGPT та адаптивних систем навчання для підтримки персоналізованого та інклюзивного навчання, підкреслюючи потенціал діалогових інструментів. Адаптивні навчальні симуляції на основі штучного інтелекту, інноваційний підхід до розробки завдань та передові методи оцінювання ще раз підтверджують можливості для вдосконалення компетентностей майбутніх учителів у сфері адаптивного, орієнтованого на учнів навчання. Окрім підвищення ефективності навчання, інструменти штучного інтелекту також сприяють розширенню можливостей учителів та рефлексивній практиці при розробці адаптивного та справедливого навчання математики. Проте залишаються значні виклики, зокрема поширені прогалини в обізнаності вчителів щодо штучного інтелекту, етичні занепокоєння стосовно конфіденційності даних, упередженості алгоритмів та прозорості, а також педагогічні ризики, пов'язані з автоматизацією та поверхневим навчанням. Крім того, постійні обмеження щодо зручності використання та дизайну ускладнюють ефективне впровадження штучного інтелекту. Цей огляд підкреслює важливість розробки цільових систем підвищення кваліфікації, сприяння теоретично обґрунтованим дослідженням та створення комплексних політичних рекомендацій. Рекомендації наголошують на долучення критичного рефлексування та грамотності в галузі ШІ до підготовки вчителів, розвитку механізмів співпраці між людьми та ШІ, а також забезпечення чітких етичних стандартів. Цей огляд надає освітянам, політикам та дослідникам міцну, засновану на фактичних даних основу для ефективного використання трансформаційного потенціалу ШІ, одночасно забезпечуючи освітню цілісність у підготовці вчителів математики.

Ключові слова: штучний інтелект (ШІ); підготовка вчителів математики; адаптивне навчання; діалогові агенти; етичні міркування.

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