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RESEARCH ARTICLE

Empowering K-12 Mathematics Teachers With Artificial Intelligence: A Systematic Review of Insights, Applications, and Challenges

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ABSTRACT The integration of artificial intelligence (AI) into education is rapidly transforming teaching practices across various subjects, including mathematics. However, research specifically focusing on K-12 mathematics teachers' use of AI remains limited, and this study fills this gap. Therefore, this systematic review explores the current practices of AI integration among K-12 mathematics teachers, focusing on a range of factors, such as demographics, research methodologies, AI tools, models, mathematical content, and the challenges encountered in this process. Following PRISMA guidelines, 18 articles published between 2020 and 2024, focusing on the integration of AI in education by K-12 mathematics teachers, were analysed from WOS, Scopus, and arXiv. The value of this study lies in the following findings: The research focuses on pre-service teachers, especially from the United States and China, which is also the main development trend in the future. The selected studies often utilized quantitative, qualitative, and mixed-methods approach, applying models such as the Technology Acceptance Model (TAM) to measure acceptance and adopting frameworks such as TPACK to guide teachers in effectively integrating technology in their teaching. Prominent AI tools frequently integrated into educational settings include ChatGPT and Intelligent Tutoring Systems (ITSs). However, there are also limitations, such as ITSs research often focusing on hypothetical applications rather than direct implementation in the classroom. Furthermore, the review emphasizes the absence of specific mathematical content or tasks for K-12 teachers, especially in secondary schools where barriers were noted regarding teacher-specific, tool-specific, and systemic issues. This underscores the necessity for professional development, improved AI tools, and comprehensive systemic frameworks.

INDEX TERMS Artificial intelligence (AI), systematic review, K-12 mathematics education, mathematics teachers, teacher professional development.

I. INTRODUCTION

Mathematics is a core subject for cultivating logical thinking and problem-solving abilities. In the classroom environment, students' learning of mathematics largely depends on the exchange of ideas between students and teachers. Learning mathematics is often accompanied by logic and abstraction, which makes it difficult for students to learn [1]. This can be attributed to differences between reality and perception of reality [2]. Equally, effective mathematics teaching requires teachers to engage with and respond to students' ideas [3], which simultaneously aid students in overcoming

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logical thinking barriers and enhances higher-order thinking skills (HOTS) through clear explanations, engaging methods, and practical activities [4]. This further highlights the importance of the role of teachers to students, and teacher education has gradually introduced emerging technologies to train pre-service teachers (PST) and in-service teachers (IST). Moreover, the classroom is no longer the only channel to guide students, and teacher education has also shifted from traditional classrooms to online classrooms. The traditional teacher-student relationship has recently evolved into a new interactive model of "teacher-AI-student", which has put forward new requirements for the role and skills of teachers. Undoubtedly, AI has significantly transformed teaching and learning practices [5], [6]. AI-driven tools encompass a range of intelligent systems and technologies, including generative AI tools (e.g., Ernie Bot and ChatGPT) and adaptive learning platforms (e.g., Khan Academy). These innovations have been consistently developed with the primary objective of enhancing educational practices [7], [8], [9] and coupled with shifts in the educational landscape, has necessitated a global re-evaluation of pedagogical approaches across all levels of education [10]. For example, GPT-4 by OpenAI currently offers capabilities such as interpreting textual and visual information and solving mathematical problems. Squirrel AI Learning, an example AI-driven personalization tool have been found to improve learning outcomes when compared to traditional classroom instruction [11].

Integrating AI into mathematics education can provide students with personalized learning experiences [12], adaptive feedback [13], and real-time assessment [14]. It is crucial for students to thoroughly understand the logic behind the answers in math classes [12]; therefore developing AI models that provide transparency and explainability is crucial to improving the quality of learning. However, successful implementation requires careful consideration of ethical implications [15], teacher training, and the development of AI-specific pedagogical strategies. It is believed that teachers must possess knowledge to understand, demonstrate, and evaluate results through AI based tools [16]. Nevertheless, educators and researchers are only beginning to explore how best to apply AI to impact classroom teaching and learning, and little is known about teachers' use of AI-based tools in education [17], [18].

Likewise, teachers' expertise, motivation, and attitude are also key factors in technology integration [19], and there is growing recognition that it is necessary to equip teachers with the necessary skills to effectively utilize these technologies. A growing body of research focuses on teachers' acceptance of AI-based technologies such as chatbots and automated exam grading [20]. AI literacy, as an emerging field, is closely related to the professional development of teachers and requires them to update their content and pedagogical knowledge. For instance, UNESCO released the "Teacher AI Competency Framework", which aims to help assess teachers' existing AI capabilities and determine expected professional learning goals by providing a basic reference for educators to understand and develop AI literacy [21].

AI literacy, as a part of K-12 curriculum, and the impact of AI and data-driven practices on individuals and society make it a relevant topic in K-12 education. Therefore, it is crucial to study how teachers in K-12 education understand and integrate AI. Recognizing this need, OpenAI launched a free online course titled "ChatGPT Foundations for K–12 Educators" that aims to assist K-12 teachers in integrating ChatGPT technology into their teaching practices to enhance efficiency and quality [22]. These initiatives highlight the importance of preparing teachers to develop knowledge, skills, and self-efficacy for using AI in instruction, and therefore there is the need to integrate AI tools, skills, and lessons into the K-12 curriculum, including mathematics [23].

However, K-12 mathematics teachers' use of AI is still in its early stages, and its AI integration is part of a larger trend of incorporating AI and computational thinking into various subjects. Furthermore, there are concerns regarding AI tools' reliability in generating precise mathematical solutions [24]. The role of teachers in educational integration of AI-based tools has been neglected [25]. Existing research on AI in K-12 mathematics teacher education is fragmented, with studies varying in focus across educational stages, geographic regions, AI tools, and instructional models. Therefore, a systematic literature review is necessary to consolidate existing knowledge, examine the educational contexts in which AI is being studied, and provide evidence-based recommendations for its integration in K-12 mathematics teaching and learning. The research questions based on the background and current status could be framed as follows:

a) What educational stages and countries have been studied regarding the role of AI in K-12 mathematics teachers' practices?
b) What research methods have been employed in studies focusing on AI for K-12 mathematics teachers?
c) What AI tools, technologies or related models/framework have K-12 mathematics teachers adopted in their teaching practices?
d) What mathematical tasks or content are currently being studied in relation to AI integration in K-12 mathematics education?
e) What challenges have been identified in the integration of AI for K-12 mathematics teachers?

These questions construct a panoramic "status map" that aims to fill the gaps that have not been systematically studied, gain a comprehensive understanding of the current status of AI integration in K-12 mathematics teacher education, and identify areas for future research and development. Exploring these aspects will offer insights into how AI can be effectively utilized to support and enhance teachers' teaching and learning, ultimately contributing to the advancement of more effective educational practices for mathematics teachers.

II. MATERIALS AND METHODS

A. PRISMA FRAMEWORK AND LITERATURE SOURCES

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were adopted to ensure the systematicity and transparency of the study. PRISMA is a set of reporting guidelines for systematic reviews and meta-analyses designed to help researchers report their research systematically and transparently [26]. The core tools of PRISMA include detailed flowcharts that clearly show the steps of literature screening, including database retrieval, literature deduplication, preliminary screening, full-text review, and other stages. This review primarily screens literature from Web of Science (WOS) and Scopus as they cover a broad range of subject areas and provide high-quality academic resources. Additionally, literature from arXiv, an open-access repository of peer-reviewed electronic preprints, was included. ArXiv is a leading platform for researchers to share their latest findings before formal publication, making it a valuable source for cutting-edge research [27]. This inclusion enables the capture of emerging trends and developments in the field that may not be represented in traditional databases like WOS and Scopus.

B. SYSTEMATIC REVIEW PROCESS FOR SELECTING ARTICLES

1) IDENTIFICATION

The systematic review process for selecting relevant articles in this study involves three stages, with the search conducted at the end of December 2024. The first stage involves keyword identification and retrieving related terms based on a thesaurus and previous studies. It is important to note that some articles may not include grade information such as "K-12," "primary," or "secondary" in the subject. Additionally, articles focused on mathematics teachers may not explicitly mention the term "mathematics teachers" in the title, requiring broader terms like "mathematics education." To ensure comprehensive coverage of literature related to "K-12 mathematics teachers and artificial intelligence," Boolean operators (AND, OR) and wildcards ("∗") were used to optimize search results in WOS, Scopus, and arXiv. The search string ("AI" OR "Artificial Intelligence") AND ("Mathematics/Math Teacher" OR "Mathematics/Math instructors" OR "Mathematics Education") was employed, followed by a search for "K-12" in subsequent steps to ensure access to high-quality literature on AI applications for K-12 mathematics teachers. The search results yielded 98, 232, and 0 articles from WOS, Scopus, and arXiv, respectively. Although receiving 0 results from arXiv using the same search string was unexpected, this outcome indirectly underscores the significance of developing mathematics teachers in the AI context. In the first stage of the systematic review, a total of 330 articles were retrieved.

2) SCREENING

After removing 32 duplicate articles, the second stage involved screening 298 articles based on several inclusion and exclusion criteria established by the researchers. A review of journal publication years in WOS revealed 11 relevant articles published before 2019. AI education began to develop rapidly in 2020; consequently, the timeline for this study was set from 2020 to 2024. The following criterion focused on the type of literature. Only journal articles (research articles) were included, as they are the primary source of empirical data. Thus, articles in the form of systematic reviews, reviews, books, book chapters, and conference proceedings were excluded. Additionally, this review focused only on articles published in English. Studies published in related fields, such as social sciences, educational technology, and educational psychology, were selected to increase the likelihood of retrieving relevant articles while excluding irrelevant fields like electronics and biology. As a result, 179 articles were excluded based on these criteria.

3) ELIGIBILITY

The third stage was the qualification review stage, and 119 articles were prepared. At this stage, it is more important to thoroughly check the titles, abstracts, and main contents of all articles to ensure that they meet the inclusion criteria and are suitable for use in this study to achieve the goals of this study. The main exclusions were articles that "There are no articles on AI in math education, or no teachers in K-12 or no research content in K-12", "only broadly describe K-12 education", "students surveyed, but teacher data is used as auxiliary" and "the research subjects are students or experts". Therefore, 69 articles were excluded (based on title and abstract). Next, the researchers carefully checked each paper based on the full text, confirmed the content, and removed 32 articles. Finally, 18 articles were available for analysis (see Figure 1).

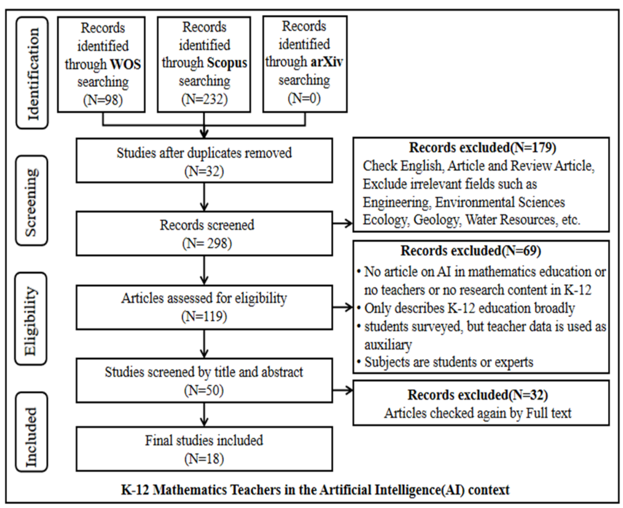

FIGURE 1. Article selection process for bibliometric mapping analysis and systematic review.

C. DATA PROCESSING AND ANALYSIS

This study conducted an integrative review, one of the review techniques that analyzes and synthesizes different research designs (qualitative, quantitative, and mixed methods). These designs can be addressed by converting one type into another, i.e., qualitative, quantitative, or quantified qualitative data. This study adopted a mixed method approach, combining quantitative descriptive statistics to solve research questions a) and qualitative content analysis Research questions b)-e). The advantage of this approach is that it provides a comprehensive overview while enabling an in-depth understanding of specific content.

III. FINDINGS

A. EDUCATIONAL STAGES AND COUNTRIES STUDIED

Figure 2 illustrates the geographical distribution and frequency of studies involving K-12 mathematics teachers in the AI context. The different colors in Figure 2 represent the frequency of mentions, with darker colors indicating higher numbers. The numbers marked on the map show the frequency of studies in each country (e.g., four studies (N = 4) in the United States, three (N = 3) in China, and one each in Nigeria, Jordan, Finland, United Arab Emirates, Turkey, Zambia, Norway, Australia, South Korea, Canada, and Germany). Figure 3 shows the distribution of teaching stages among the studied mathematics teachers, where ten (N = 10) studies focus on pre-service teachers (PST), three (N = 3) on primary school, five (N = 5) on secondary school, one on both primary and middle school, and one on K-12 teachers. In addition, there are two (N = 2) studies on primary school mathematics teachers, two (N = 2) on secondary schools, one of which is for middle school and four (N = 4) studies on K-12 mathematics teachers. 10 of the 18 studies on mathematics teachers focused on PST while focusing on different teaching stages (primary, secondary and K-12). This indicates that current research aims to gain a comprehensive understanding and improvement of global mathematics teaching practices, while also highlighting the key role of future teachers in shaping education.

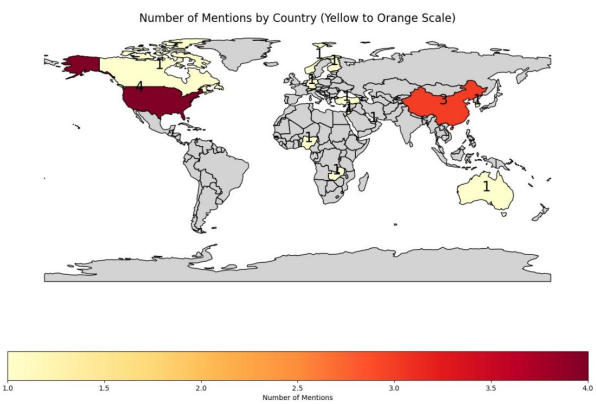

FIGURE 2. Distribution and number of mathematics teachers studied.

B. RESEARCH METHODS ADOPTED

The summary results listed in **Appendix** (TABLE 1) provide valuable insights into how AI can support K-12 mathematics teachers and inform future research and policymaking. The studies on AI for K-12 mathematics teachers employed various methods, including seven studies (N = 7) adopted quantitative methods (e.g., PLS-SEM, regression analysis), five studies (N = 5) employed qualitative approaches (e.g., thematic analysis, comparative analysis), and six studies (N = 6) implemented mixed-methods designs. Quantitative methods evaluated behavioral intentions, proficiency, and attitudes toward AI tools, while qualitative studies explored teacher interactions with AI systems and their pedagogical implications. Mixed methods studies combined these approaches to comprehensively understand AI's impact on teaching practices and knowledge development.

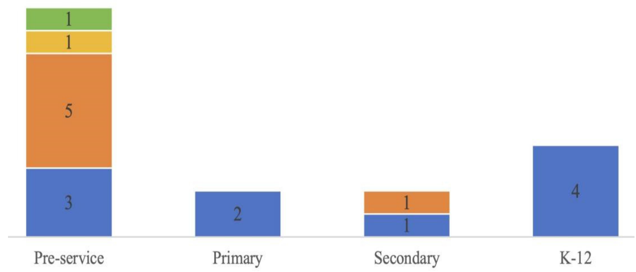

FIGURE 3. Distribution of mathematics teachers studied's teaching stages.

C. AI TOOLS, TECHNOLOGIES, AND FRAMEWORKS UTILIZED IN K-12 MATHEMATICS TEACHER RESEARCH

1) MODELS AND FRAMEWORKS

The related models or theoretical frameworks to investigate the integration of AI and digital technologies in K-12 mathematics teacher education could be mainly categorized as investigating general technology use or specific AI tool adoption in K-12 mathematics education.

a: GENERAL TECHNOLOGY ADOPTION MODELS OR FRAMEWORKS

These models are traditionally used to understand how educators integrate AI technology into their teaching. Technology Acceptance Model (TAM) has been applied to examine factors influencing the adoption and utilization of technology, focusing on variables such as teacher attitudes, contextual challenges, and external influences [5]. Similarly, a study in 2024 investigated mathematics teacher educators' proficiency and willingness to integrate technology into instruction, emphasizing the role of teacher preparedness in successful technology adoption [7]. The Technological Pedagogical Content Knowledge (TPACK) framework, which evaluates teachers' ability to integrate technology into pedagogy and subject content, has also been employed in AI-related studies. Mathematics teachers' content knowledge (CK) and pedagogical content knowledge (PCK) improved following the implementation of Intelligent Tutoring Systems (ITSs), leading to enhanced student learning outcomes [28]. Additionally, a 2022 study combined TPACK and the Stages of Concern (SoC) model, which is a component of the Concerns-Based Adoption Model (CBAM), to assess teachers' attitudes and behaviors toward technology [29]. Using a questionnaire grounded in both frameworks, the study effectively measured teachers' knowledge structure (TPACK) alongside their concerns and readiness (SoC) regarding AI integration.

b: FRAMEWORKS FOR UNDERSTANDING AI ADOPTION AND USE

While TAM, TPACK, and SoC provide broad insights into technology integration, their application to AI is indirect. These frameworks do not specifically focus on AI but rather serve as general models for understanding technology adoption in education. However, recent studies have begun to adapt these frameworks to explore AI-specific adoption patterns. For instance, a 2024 study adapted the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) model to examine pre-service mathematics teachers' behavioral intentions and usage patterns related to AI chatbots [8]. Their study emphasized how foundational experience with AI tools influences educators' willingness to incorporate them into instructional practices. Similarly, the Willingness, Skills, Tools (WST) framework was employed to investigate the key factors affecting teachers' adoption of digital tools in mathematics education [30]. The WST model highlights the interplay between teacher readiness, technological proficiency, and available digital resources, offering insights into how educators navigate the challenges of AI integration.

2) AI TOOLS

The integration of AI tools in K-12 mathematics teacher education is gaining attention as researchers explore technologies like Intelligent Tutoring Systems (ITSs), generative AI chatbots, and virtual student simulations to enhance student engagement, personalized learning, and adaptive feedback.

a: ITSs IN MATHEMATICS EDUCATION

ITSs have been widely recognized for their ability to provide adaptive learning experiences in mathematics education [31], [32]. ITS is computer-based and the standard way to take advantage of it is to use a computer to input information through a keyboard and mouse [33], provide individualized instruction by modeling students' cognitive and psychological states. ITSs such as ALEKS, MATHia, and Khan Academy leverage AI-driven algorithms to assess student progress and tailor instruction accordingly [34]. Although ITSs were originally designed for students, in 2 of the 18 articles (N = 2), the application of ITSs shifted to teachers, but with a different focus. A 2022 study focuses on how PST integrate ITSs in mathematics teaching, and the relationship between this integration and their teaching knowledge (TPACK) and concerns [29]. The study found that 55% of pre service teachers position ITS as ''servants'' or ''partners'', meaning they only use it as an auxiliary tool, while 39% of teachers position ITSs as ''partners'', meaning they use the data provided by ITSs to adjust teaching activities to be more interactive and student-centered. This will affect how they use ITSs to adjust teaching practices, thereby affecting teaching quality and students' learning experience. Copur-Gencturk et al. [28] developed a scalable and interactive Teacher Professional Development (PD) project that simulates real mentor dialogue strategies through ITSs, providing feedback and prompts to teachers for specific teaching tasks of CK and PCK. This system is also based on the Expectation and Misconception Tailoring (EMT) framework, which identifies teachers' knowledge levels through conversational interaction and provides targeted prompts and feedback to promote teachers' understanding and application of core concepts in mathematics teaching. While ITSs are prominent in digital learning environments, their full integration into K-12 mathematics classrooms remains an area of ongoing research, teacher engagement is essential to achieving their full potential.

b: AI-POWERED CHATBOTS AND VIRTUAL STUDENT SYSTEMS

Zhang et al. [3] employed an AI-driven virtual student system, based on an advanced version of the Generative Pre-trained Transformer (GPT) model, to simulate real classroom interactions. Similarly, Lee and Yeo [35] incorporated IBM Watson Assistant into their research, developing a virtual student named ''Jiwoo'' to assist pre-service mathematics teachers. It was reported that by interacting with Jiwoo, teachers could practice identifying student misconceptions and develop strategies for formulating complex questions, thus enhancing their pedagogical skills in AI-assisted learning environments. Equally based on the findings we only observed N = 1 study using AI robot (chatbot:IBM Watson) Conduct specific research focused on mathematics teachers, while other studies only introduce AI tools such as AI robots.

c: ChatGPT AS A MULTIFUNCTIONAL AI TOOL IN MATHEMATICS EDUCATION

Among AI-driven tools, ChatGPT has emerged as a focal point in mathematics education research where it serves two primary roles [36], [37], [38]:

i. Large Language Model (LLM) – ChatGPT powers natural language processing, enabling it to generate explanations, analyze mathematical problems, and support learning through interactive responses [36].

ii. AI-Based Educational Tool – ChatGPT transforms its LLM capabilities into practical applications for real-time tutoring, automated problem-solving, and content generation, providing students and teachers with instant instructional support [37], [38].

Wijaya et al. et al. [9] highlighted the growing adoption of AI chatbots such as ChatGPT and Ernie Bot, noting their potential in facilitating student engagement and instructional support. However, their study did not focus on the detailed functionality of these tools but rather positioned them as representative examples of a broader AI trend in education. Despite these advantages, concerns persist regarding the reliability of AI-generated mathematical solutions.

D. MATHEMATICAL TASKS AND CONTENT FOR K-12 MATHEMATICS TEACHERS IN AI CONTEXT

The integration of AI into K-12 mathematics teacher education has facilitated diverse mathematical tasks and contents as discussed below:

1) GENERATIVE AI (CHATGPT) POWERED PROBLEM-SOLVING IN MATHEMATICS

Sapkota and Bondurant [38] studied mathematics teachers' ability to use the area model method using ChatGPT to solve elementary school problems involving fraction multiplication and examined its accuracy and teaching usefulness. Similarly, Getenet [37] evaluated ChatGPT's strategic approaches to solving a mathematical word problem and by analyzing multiple solution strategies, the study provided insights into how ChatGPT processes logical reasoning in mathematical contexts. Additionally, Dilling and Herrmann [36], examined ChatGPT's role in assisting pre-service mathematics teachers in constructing mathematical proofs in geometry based on Interior Angle Theorem and Base Angle Theorem. Their findings highlighted how AI tools can scaffold proof construction and improve conceptual understanding among future educators.

2) AI-SUPPORTED TEACHER TRAINING

Beyond focused problem-solving, AI has also been leveraged to support mathematics teachers' pedagogical development. Copur-Gencturk et al. [28] examined how ITSs facilitated teacher learning and instruction on ratios and proportional relationships, a fundamental topic in middle school mathematics (6th-7th grades). The study focused on two key teacher knowledge domains which were CK and PCK. While the study did not directly assess student performance, it underscored how ITSs enhance teacher expertise, aiming to improve classroom instruction through AI-driven professional development. AI has also been utilized to improve how teachers identify student misunderstandings and provide targeted instruction. Lee and Yeo [35] examined how pre-service mathematics teachers interacted with AI chatbots to practice diagnosing student misconceptions in fractions. Through simulated AI-assisted dialogues, teachers were able to refine their questioning strategies, enhancing their ability to guide student learning effectively.

3) COMPUTATIONAL THINKING DEVELOPMENT AND AI COMBINED WITH AR ASSISTED LEARNING

The role of computational thinking (CT) in AI-driven mathematics education has also been a growing area of research. Nordby et al. [41] described CT as a "soft start" for later engagement with AI. Lu and Zheng et al. [39] incorporated CT into the evaluation of HOTS, highlighting its relevance for developing problem-solving and logical reasoning capabilities. Another AI-driven innovation in mathematical teaching and learning is the use of AI-assisted augmented reality (AR) for geometric reasoning. Uygun et al. [2] explored how AR, combined with AI, was used to teach The Platonic Solids, helping PST advance from Level 1 to Level 3 and Level 4 in geometric thinking. These findings suggest that AI-enhanced AR can deepen geometric comprehension by enabling interactive exploration of three-dimensional mathematical concepts.

E. CHALLENGES IDENTIFIED IN AI INTEGRATION OF K-12 MATHEMATICS TEACHER

The integration of AI into K-12 mathematics teacher education presents a range of challenges, affecting both teachers' adoption of AI tools and the effectiveness of AI-driven instructional methods. These challenges can be categorized into pedagogical barriers, technological limitations, teacher training gaps, ethical concerns, and cognitive impacts.

1) PEDAGOGICAL BARRIERS TO AI ADOPTION

One of the most prominent challenges in AI integration is the difficulty in transitioning from traditional to AI-supported teaching. Zhang et al. [3] highlighted that PST struggle to shift from conventional instructional methods to AI-responsive teaching practices, particularly when using AI for classroom simulations. Similarly, Mao [5] found that teachers face internal barriers, such as limited Technological Pedagogical Content Knowledge (TPACK) and negative attitudes toward AI, in addition to external obstacles, such as policy constraints, resource limitations, and lack of community support. AI's role in mathematics education also raises concerns about its effectiveness in supporting higher-order thinking skills. Sapkota and Bondurant [38] found that ChatGPT tends to generate procedural tasks with limited cognitive demand, while Shin [29] reported that teachers often use ITSs reactively rather than proactively, limiting their potential to foster deep learning.

2) TECHNOLOGICAL LIMITATIONS AND AI RELIABILITY

Studies have shown AI's limitations in generating accurate and contextually appropriate responses in mathematical problem-solving. Egara and Mosimege [17] identified ChatGPT's reliability issues, particularly in solving complex mathematical problems, leading to teacher hesitation in using AI tools. Getenet [37] similarly reported

ChatGPT's difficulties in producing contextually accurate problem-solving strategies. Moreover, AI-generated mathematical proofs often require manual intervention for accuracy [36], and Lee and Yeo [35] observed that early chatbot iterations provided limited coverage and repetitive responses, reducing their effectiveness in classroom simulations. Uygun et al. [2] further highlighted technical difficulties with AI-assisted AR, such as producing correct Python codes and transferring them to Blender, which created obstacles for teachers trying to implement AI-based learning activities.

3) TEACHER TRAINING GAPS AND RESISTANCE TO AI ADOPTION

Teachers' lack of AI literacy and limited training opportunities pose significant barriers to AI integration. Wardat et al. [8] found that teachers experience increased workload and pressure when using AI tools compared to traditional methods, largely due to insufficient training programs and awareness courses. Nordby et al. [41] noted that many primary teachers struggle with integrating CT into mathematics instruction, further limiting AI's potential impact in early education. Mukuka [7] found that mathematics teacher educators display varying levels of proficiency and willingness to adopt technology, affecting AI's integration into curricula. Alissa and Hamadn [40] similarly reported a lack of specialized AI knowledge among teachers, coupled with limited availability of AI applications and inadequate institutional support, which further hinders implementation.

4) ETHICAL, PRIVACY, AND EQUITY CONCERNS

Concerns over AI's ethical implications and data security remain a significant challenge for educators. Pörn et al. [30] reported that teachers express concerns about AI's potential risks, including increased inequality and data security vulnerabilities. Similarly, Wijaya et al. [8] highlighted that while higher AI literacy and trust among mathematics teachers encourage adoption, they also lead to over-reliance on AI, potentially diminishing critical 21st-century skills such as self-confidence, problem-solving, creativity, and collaboration. The issue of equitable access to AI resources was also raised by Alissa and Hamadn [40], who pointed out that the lack of resources and institutional support for AI implementation exacerbates educational disparities.

5) COGNITIVE AND INSTRUCTIONAL CHALLENGES

AI integration was found to presents cognitive and instructional challenges that affect both teachers and students. Copur-Gencturk et al. [28] found that teachers struggled to align improvements in CK and PCK with practical teaching, leading to concerns about over-reliance on AI-driven instruction. Moreover, Wijaya et al. [8] emphasized that while AI chatbots improve instructional efficiency, they can negatively impact teachers' problem-solving and critical thinking skills if used as a primary teaching tool. Porn et al. [30] further raised concerns about ethical and privacy risks associated with AI in the classroom, reinforcing the need for responsible AI implementation strategies.

IV. DISCUSSION

A. DISCUSSION OF EDUCATIONAL STAGES, COUNTRIES, AND MATHEMATICAL CONTENT IN K-12 MATHEMATICS TEACHER WITH AI CONTEXT

Research on K-12 mathematics teachers in the context of AI, based on research question a), mainly focuses on PST (10 out of 18 studies), highlighting the global emphasis on AI-integrated teaching for future educators. Geographically, the United States and China lead in research volume, indicating their focus on the development of future teachers. America and China can serve as a reference for other regions that lack research and bold efforts in this regard. The studies covered different teaching stages: elementary school, secondary school, and K-12. However, for the research subjects of K-12 mathematics teachers, the content of designing AI literacy, such as mathematics teachers' views, usage and beliefs on AI, is usually examined, and mathematics content is not included in the research, see [8], [9], [30], [40]. Therefore, most of these contents are superficial, and there has been no specific research in the field of mathematics, such as artificial literacy research on mathematical statements. Most of them are in attitude, motivation, and acceptance, without more delicate emotional research.

Research question d) revealed that too little attention has been paid to secondary school mathematics tasks or content. The studies focus on primary school mathematics content: primary school students use the area model method to perform fraction multiplication [38], algebra or equation problems [37], and geometry proof problems [36]. Nordby et al. [41] emphasizes the importance of CT in primary school, and Copur-Gencturk et al. [28] focuses on ratio and proportion problems in middle school. In Uygun et al. [2]'s study, Platonic solids were not emphasized on grade level, but the article stated that the study mentioned this geometric thinking skill from primary school to university grade level. Among them, middle school content is rarely covered, and high school content is not specifically studied.

B. DISCUSSION OF RESEARCH METHODS AND AI TOOLS/FRAMEWORKS ADOPTED IN K-12 MATHEMATICS TEACHER

Further discussion of research questions b) and c) reveals diverse methodologies. Quantitative studies examined AI adoption factors, teacher proficiency, and behavioral intentions toward chatbots like ChatGPT and Ernie Bot, see [7], [8], [9], [30], [39], [40]. Qualitative studies explored specific mathematical tasks, computational thinking, and

TABLE 1. Research methods, AI tools/method/framework, and results in AI integration for K-12 mathematics teachers.

Author	Aim	Method	AI Tool/ Model or Framework Used	Result
Mao, L. [5]	Investigate internal and external influences on AI adoption in primary mathematics education.	Quantitative (PLS-SEM)	Integrate TAM,TPACK	Teacher attitudes and TPACK significantly influence AI adoption. Emphasizes the role of systemic support.
Zhang et al. [3]	Explore pre-service teachers' (PST) use of AI-supported virtual simulations to enhance responsive teaching.	Mixed-methods,(Sequential analysis; transcripts, notes and semi-structured interviews)	AI-powered virtual students	AI-supported simulations improve PSTs' responsive teaching skills but highlight challenges in transitioning to responsive practices.
Egara & Mosimege [17]	Investigate perceptions and challenges of secondary school mathematics teachers on integrating ChatGPT in mathematics teaching.	Mixed-methods(Systematic survey; interviews)	ChatGPT	Teachers perceive ChatGPT as useful but face challenges in its integration due to reliability and implementation concerns.
Sapkota & Bondurant [38]	Assess the cognitive demand of ChatGPT-generated mathematical tasks.	Qualitative descriptive approaches(collaborative self-study)	ChatGPT	ChatGPT-generated tasks are procedural with limited cognitive demand and occasional inaccuracies.
Mukuka [7]	Analyze mathematics teacher educators' proficiency and willingness to integrate technology.	Quantitative (Questionnaire; PLS-SEM)	TAM,TPACK	Teacher proficiency and attitudes toward technology vary, with institutional support critical for effective technology use.
Wijaya et al. [8]	Examine factors influencing Chinese pre-service mathematics teachers' adoption of AI chatbots.	Quantitative (Questionnaire;SEM)	AI Chatbots (ChatGPT, Ernie Bot); UTAUT2	Performance expectancy (PE)significantly influences behavioral intention to adopt AI chatbots.
Nordby et al. [41]	Investigate primary mathematics teachers' understanding of computational thinking (CT).	Qualitative(Observations ;interviews,Thematic analysis)	Not specified	Teachers' knowledge of CT is limited, affecting its integration into mathematics teaching.
Getenet [37]	Compare problem-solving strategies of ChatGPT and pre-service teachers in primary mathematics education.	Qualitative (Comparative analysis using thematic)	ChatGPT	PSTs use diverse strategies; ChatGPT's outputs are less accurate but demonstrate potential for instructional support.
Shin [29]	Explore prospective teachers' concerns and positioning of Intelligent Tutoring Systems (ITSs) in mathematics teaching.	Mixed-methods (TPACK-21 and SOC questionnaires;mathematics lesson plan）	Intelligent tutoring systems(ITSs);TPACK, Stages of Concern（SoC）	Teachers are more likely to use ITSs as a servant rather than a partner; TPACK influences their integration approaches.
Nongni [10]	Focusing on the preparation and variable analysis of pre-service mathematics teachers in distance learning planning.	Qualitative	Not specified	The choice of technological tools used in distance learning in mathematics depends largely on the conceptual analysis of the mathematics to be taught.
Dilling & Herrmann [36]	Explore how pre-service mathematics teachers use ChatGPT for mathematical proofs in geometry.	Qualitative(Thematic analysis,MAXQDA).	large language models (LLMs); ChatGPT	Identified pre-service teachers' interaction patterns with ChatGPT, highlighting challenges and potential in proof construction.

TABLE 1. ***(Continued.)*** **Research methods, AI tools/method/framework, and results in AI integration for K-12 mathematics teachers.**

Copur-Gencturk et al. [28]	Investigate the role of ITSs in enhancing middle school mathematics teachers' CK and PCK and its effects on student learning.	Mixed method (RCT design; regression analysis); (interaction between teachers and ITSs, feedback in iteration).	ITSs,TPACK(CK,PCK)	Teachers who used ITS showed improved CK and PCK, resulting in better student outcomes.
Wijaya et al. [9]	To identify distinct profiles of AI literacy and trust among mathematics teachers and examine their relationships with AI dependency and 21st-century skills.	Quantitative (Latent Profile Analysis, LPA)	None specified (focused on AI literacy and trust)	Five distinct profiles of AI literacy and trust were identified. Higher AI literacy and trust were associated with increased AI dependency but negatively correlated with 21st-century skills such as self-confidence, problem-solving, critical thinking, creative thinking, and collaboration.
Uygun et al. [2]	To examine the effectiveness of AI-assisted AR activities on the development of pre-service teachers' geometric thinking.	Mixed-methods (test result analysis and interviews)	ChatGPT, Blender, MyWebAR	AI-assisted AR activities significantly improved pre-service teachers' conceptualization and geometric thinking levels, with participants advancing from Level 1 to Level 3 and Level 4 in geometric thinking.
Pörn et al. [30]	To investigate digitally skilled K-12 mathematics teachers' attitudes towards and expectations of AI in the classroom.	Quantitative (Survey with mixed methods)	Will, Skill, Tool (WST) framework	Teachers showed interest and openness towards AI tools but emphasized potential risks. They highlighted the need for systemic support and ethical considerations in AI implementation.
Wardat et al. [1]	To explore mathematics teachers' perspectives on the implementation of AI systems and applications in Abu Dhabi schools.	Quantitative (SEM,SPSS)	None specified (focused on studying teachers' views on the use of AI)	Teachers recognized the potential benefits of AI in education but faced significant challenges such as increased workload and lack of technical support. They emphasized the need for training and resources.
Alissa and Hamadn [40]	To identify the level of science and mathematics teachers' employment of AI applications in the educational process in Jordan.	Quantitative (Descriptive approach)	None specified (focused on teachers' usage of AI, different from gender and specialization)	Teachers' use of AI applications was moderate. Female teachers showed higher levels of AI application use than male teachers, but no significant differences were found based on specialization
Lee and Yeo [35]	To develop an AI-based chatbot to enhance pre-service teachers' responsive teaching skills in mathematics.	Mixed-methods(Design-based research (DBR) with two iterations)	IBM Watson Assistant	The chatbot effectively covered 97% of user questions and provided realistic responses. It helped pre-service teachers practice responsive teaching skills through simulated interactions with a virtual student.

distance learning planning, see [10], [36], [37], [38], [41]. Mixed-methods studies combined quantitative and qualitative approaches (see [2], [3], [17], [28], [29], [35]) to address both measurable outcomes and contextual insights into AI integration, Frameworks such as TAM, TPACK, UTAUT2, and SOC were widely used, with TPACK often integrated with TAM or SOC to analyze multidimensional factors in technology adoption. ChatGPT was the most frequently discussed tool, serving as both a LLM and an AI tool, while ITSs were also explored, highlighting their potential for CK and PCK development. At the same time, research on combining AI-robot with the perspective of mathematics teachers has not yet been fully started, with only one study. It is indeed difficult to explore new technologies sometimes.

However, the study by Zhang et al. [3] enhanced pre-service teacher's responsive teaching skills with artificial intelligence; its reliance on simulated environments limited its generalization ability. Similarly, research on ITSs has often focused on hypothetical applications rather than direct classroom implementation. Shin [29] reported that pre-service mathematics teachers were tasked with designing lesson plans that incorporated ITSs such as ALEKS and Khan Academy. These tools were explored through simulations rather than tested in real-world K-12 classroom environments, highlighting a gap between theoretical application and practical integration. Current research remains in the early stages, focusing on foundational insights into adoption, teaching applications, and challenges.

C. DISCUSSION OF THE CHALLENGES IDENTIFIED IN AI INTEGRATION OF K-12 MATHEMATICS TEACHER

For Research Question e), the challenges faced by K-12 mathematics teachers in the context of AI can be categorized into three types: (1) Teacher-specific challenges include limited knowledge and skills, as well as resistance and negative attitudes toward AI adoption. (2) AI tool-specific challenges involve issues with the reliability and accuracy of tools, as well as a focus on procedural rather than cognitively demanding tasks. (3) Systemic and contextual challenges encompass resource and policy gaps, inadequate planning and implementation, and the positioning of AI tools as either assistants or partners in teaching. To address these challenges, targeted professional development should be provided to enhance teachers' TPACK, CK, and PCK, focusing on real-world integration of AI in classrooms. Additionally, AI tools such as ChatGPT, ITSs and Chatbot should be improved to offer accurate, context-aware, and higher-order cognitive tasks. Finally, robust systemic frameworks are needed to bridge resource gaps, ensure equitable access to technology, and establish consistent policy support for effective AI integration in education.

D. LIMITATIONS AND FUTURE PROSPECTS

This study screened articles based on selected authoritative databases for the literature review. However, the research questions could be expanded and explored from additional perspectives, with more detailed content. As of December 2024, research on AI integration in K-12 mathematics teacher education remains limited to studies from only 13 countries. More research should be done in the future, especially in underrepresented regions such as Africa, Latin America or Southeast Asia, as well as in countries that have been studied but have been neglected. There is a pressing need for more research at the secondary school level, particularly in relation to specific mathematical content areas such as algebra and mathematical proof. While much of the current research has centred on K–12 mathematics teachers, future studies should broaden their scope to include various educational levels and teacher demographics. This would also support advancements in curriculum design and targeted professional development. As we continue to benefit from the convenience of AI technologies, it is equally important to cultivate critical thinking and maintain a strong emphasis on ethical considerations and data authenticity [6].

The literature review also revealed other important research directions, such as the integration of AI with AR [2], the perspectives of private versus public school mathematics teachers [8], [9], and comparisons of male and female mathematics teachers [40]. Future research could explore more internal comparisons among mathematics teachers. Additionally, the lack of studies on cultural and regional differences in AI adoption limits our understanding of how contextual factors influence the integration of AI tools [8], [40]. Furthermore, the scarcity of longitudinal studies restricts the ability to assess the long-term impacts of AI tools on teaching practices and student learning outcomes.

V. CONCLUSION

Mathematics teachers are an important part of students' mathematics learning, and are even more indispensable in the context of AI. Therefore, there is a need for a systematic literature review to examine the educational context of AI research and provide suggestions for its integration into K-12 mathematics teaching. The unique value of this study is that it fills the gap in the current lack of a systematic literature review on AI and K-12 mathematics teachers. We found the integration of AI in K-12 mathematics teacher education is still in its early stages, only 18 related articles were retrieved. Most studies (10 of 18) focus on PST, particularly in the United States and China, while secondary school mathematics content remains underexplored. Models or Frameworks such as TAM, TPACK, and UTAUT2 have been widely applied to analyze teacher adoption and integration of AI, highlighting both flexibility and practical challenges. Key tools like ChatGPT and ITSs show potential but are limited by accuracy and alignment with teaching practices. Future research should prioritise pre-service mathematics teachers, improve curriculum designs, and provide training. It should also aim to bridge the gap between theoretical understanding and practical application of AI tools, explore specific mathematical content at the secondary level, and pursue comparative, cross-cultural, and longitudinal studies from multiple perspectives.

APPENDIX

See Table 1.

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