Artificial Intelligence in Mathematics Teacher Education: A Systematic Review and Qualitative Synthesis of Contemporary Research Literature

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Abstract

This qualitative review critically examines the burgeoning influence of AI on pre-service and in-service mathematics teacher education. Amidst rapid technological advancements, this study leverages a systematic qualitative analysis to distill insights from various scholarly articles, book chapters, and conference proceedings published since 2015. The selection process prioritized peer-reviewed, English-language literature that directly addresses the integration and implications of AI technologies within mathematics teacher education programs. Our methodology entailed an exhaustive search across prominent academic databases, utilizing a refined set of keywords to ensure comprehensive coverage of relevant studies. The literature was meticulously coded and analyzed, facilitating a nuanced thematic analysis that identifies, categorizes, and synthesizes the complex interplay between AI and mathematics teacher education. This review sheds light on the diverse applications of AI technologies in these contexts, ranging from virtual simulations and intelligent tutoring systems to personalized learning environments and their pedagogical implications. Key findings reveal AI's benefits, including enhanced pedagogical strategies, personalized learning pathways, and improved student engagement and outcomes. Concurrently, the review elucidates significant challenges such as the digital divide, privacy concerns, and the pressing need for teacher professional development on AI utilization. The analysis culminates in a discussion on the implications of these findings for practice, highlighting the transformative potential of AI in fostering innovative educational practices while cautioning against uncritical adoption. By offering a comprehensive Synthesis of the current state of research, this review contributes to the academic discourse on technology integration in teacher education. It provides practical insights for stakeholders involved in curriculum design and professional development. Furthermore, it delineates fruitful avenues for future research, underscoring the necessity for longitudinal studies to understand AI's long-term impact on teaching practices and learning outcomes in mathematics education.

Introduction

Since the emergence of AI in 1955, the applications of AI have expanded within a rapidly evolving digital landscape, influenced by public expectations, industry leaders, and medical practitioners (Zawacki-Richter et al., 2019). Reports indicate that Artificial Intelligence in Education (AIEd) is a growing field in educational technology, highlighting its relevance in various academic domains (Chan & Zary, 2019). These references emphasize the increasing importance of AI in education, including mathematics teaching and learning, underscoring the need to explore AI's impact on mathematics teacher education.

Artificial Intelligence (AI) has been increasingly integrated into various educational domains, including mathematics teaching and learning. Studies such as those by Hidayat et al. (2022) and Xu and Ouyang (2022) have highlighted the significance of AI in enhancing STEM education, emphasizing the need to merge AI techniques with educational elements to cater to instructional and learning requirements. Voskoglou and Salem (2020) further discuss the benefits and limitations of AI compared to traditional methods in mathematics education, underlining the shift towards utilizing AI applications in teaching.

In higher education, the potential of AI to revolutionize teaching and learning is evident (Crompton & Song, 2021). Crompton and Song (2021) emphasize the transformative impact of AI in higher education, suggesting that AI significantly enhances educational practices. Popenici and Kerr (2017) delve into the broader implications of AI in higher education, pointing out that the widespread adoption of AI is reshaping the global higher education landscape.

Moreover, the ethical considerations surrounding AI in education have gained attention. Yu and Yu (2023) stress the importance of ethical considerations in integrating AI into education, reflecting the growing concerns about the moral implications of AI technologies. Additionally, Hannan (2021) discusses how AI is becoming a new source of competitiveness in higher education, indicating the need for institutions to adapt to the changing educational landscape driven by AI technologies. The research on AI in education underscores AI's transformative potential in enhancing teaching and learning practices across various educational levels, mainly focusing on mathematics education and higher education.

Significance of Study

Integrating Artificial Intelligence (AI) into mathematics teacher education marks a significant shift in educational technology, driven by rapid technological advancements and evolving pedagogical needs. The advent of AI in academic settings is reshaping methodologies and approaches in mathematics teacher education, emphasizing the critical role of AI in enhancing teaching and learning experiences. This transformative potential of AI is increasingly recognized as countries develop national AI strategies, underscoring the importance of mathematics education in contemporary and future societal contexts (Hidayat et al., 2022).

AI's capacity to offer personalized learning experiences and elevate student engagement has been a cornerstone in revolutionizing education, including mathematics teaching (Zawacki-Richter et al., 2019). The imperative for integrating AI literacy into curricula is highlighted, aiming to demystify AI for learners while elucidating its limitations and societal implications (Eguchi et al., 2021). Furthermore, the necessity for transparency in AI-powered educational technologies has been stressed, alongside a growing concern for ethical considerations amidst the rapid proliferation of AI tools (Chaudhry et al., 2022; Yu & Yu, 2023).

The impact of AI extends to STEM education, where its integration necessitates careful preparation and early exposure to AI concepts, ensuring that teachers are well-equipped to incorporate AI effectively in their classrooms (Lee & Perret, 2022; Xu & Ouyang, 2022). The role of AI as a primary driver for social and economic development further underscores the importance of enhancing learners' readiness for AI, preparing them for future success (Song et al., 2022).

The application of AI technologies within mathematics education provides educators with innovative tools and resources, enabling them to refine their pedagogical approaches and cater to the diverse learning needs of students. This is particularly relevant in tackling issues such as mathematics anxiety, where AI tools have shown promise in establishing supportive learning environments that boost teacher confidence and student engagement (Buckley et al., 2016; Türk et al., 2018).

Moreover, integrating digital technologies into mathematics education influences teacher candidates' perceptions and practices, fostering a technology-enhanced approach to teaching mathematics (Temel & Gür, 2022). The evolving educational landscape, marked by the COVID-19 pandemic and the emergence of Society 5.0, further necessitates adapting mathematics teacher education to embrace modernization and new educational paradigms (Borba, 2021; Rizqi & Dewi, 2022).

In conclusion, the incorporation of AI in mathematics teacher education heralds a new era of pedagogical innovation, enhancing teaching practices and preparing educators to navigate the complexities of a digital and technologically driven educational landscape. By embracing AI literacy, advocating for transparency, and addressing ethical concerns, educators can harness the benefits of AI to enrich mathematics teacher education, meeting the evolving educational needs of learners.

Guiding Research Questions

The guiding research questions for this study aim to explore the various dimensions and impacts of integrating artificial intelligence (AI) into mathematics teacher education. These questions are designed to uncover insights into how AI can transform teaching practices, enhance learning outcomes, and address the challenges faced by educators. The primary questions guiding this research are:

- How does the integration of AI technologies influence teaching practices in mathematics teacher education?
- What are the perceived benefits and challenges of incorporating AI into pre-service and in-service teacher education programs?
- How do AI applications enhance the learning experiences and outcomes of mathematics students?
- What ethical considerations arise from the use of AI in mathematics education, and how can they be addressed?

- In what ways can AI tools be effectively implemented to support the professional development of mathematics teachers?

Theoretical Framework

The analysis of AI's impact on teacher education is guided by theoretical perspectives such as Technological Pedagogical Content Knowledge (TPACK) and Constructivism. TPACK emphasizes integrating technology, pedagogy, and subject content knowledge for effective teaching with technology (Shu, 2016). It provides a framework for understanding the knowledge teachers need to successfully integrate technology into their teaching practices (Padmavathi, 2017). TPACK is essential for preparing and developing teachers in educational technology (Liang et al., 2013).

On the other hand, Constructivism, as a theoretical perspective, focuses on how students construct knowledge through experiences and interactions (Abdal-Haqq, 1998). It highlights the importance of active learning, student-centered approaches, and the role of the teacher as a facilitator in the learning process (Manchulenko et al., 2021). Constructivist perspectives help educators understand how students make sense of their experiences and guide teaching practices that promote meaningful learning (Windschitl, 1999). Regarding AI in teacher education, studies have shown a need to explore teachers' perspectives on teaching AI in schools (Yau et al., 2022). Additionally, AI supports teacher training and continuous professional development, enhancing teachers' skills and practices (Zhao et al., 2021). Integrating technology with constructivist pedagogy further enhances learning experiences by providing an environment for collaborative learning and knowledge construction (Chuaungo et al., 2022).

In conclusion, TPACK and Constructivism are valuable theoretical perspectives that inform the analysis of AI's impact on teacher education. TPACK provides a framework for effective technology integration, while Constructivism emphasizes student-centered learning and knowledge construction. By understanding and applying these theoretical perspectives, educators navigate the complexities of integrating AI and technology into teaching practices to enhance student learning outcomes.

Methodology

Research Design

This qualitative review systematically analyzes the impact of AI on pre-service and in-service mathematics teacher education. Our approach employs a comprehensive qualitative analysis to identify, evaluate, and synthesize findings from relevant literature. Given the exploratory nature of the review, we chose MAXQDA software, a leading qualitative data analysis tool, to facilitate the organization, coding, and thematic analysis of the collected data. This software enables the efficient handling of large volumes of text data, allowing for nuanced coding and the identification of emerging themes and patterns related to the integration and impact of AI in mathematics teacher education.

Data Sources

To ensure a broad collection of literature, we systematically searched academic databases and digital libraries, including ERIC, JSTOR, ScienceDirect, Scopus, Web of Science, and Google Scholar. The search strategy was designed to capture a wide range of publications on the use of AI in teacher education, with a particular focus on mathematics. Keywords and phrases used in the search included combinations of "artificial intelligence," "teacher education," "mathematics education," "pre-service teachers," "in-service teachers," and "technology integration in education."

Selection Criteria

The inclusion criteria for the literature were: 1) Peer-reviewed articles published in academic journals to ensure the reliability and validity of the findings, 2) Book chapters and conference proceedings that provide in-depth analyses or case studies, 3) Publications from 2015 onwards to ensure the relevance and currency of the technological applications discussed, 4) Studies focusing on using AI in pre-service and in-service mathematics teacher education programs, 5) English-language publications to maintain consistency in analysis and interpretation.

The exclusion criteria were: 1) Articles not specifically addressing AI's application in mathematics teacher education, 2) Opinion pieces and editorials without empirical evidence or comprehensive analysis, 3) Studies that focus on disciplines outside of mathematics education to maintain a focused scope of review, 4) Data Analysis Process Using MAXQDA.

Qualitative Data Analysis Process

The selected studies were imported into MAXQDA for qualitative data analysis. The analysis process involved several steps:

- *Initial Reading and Coding:* Each document was read thoroughly to understand its content comprehensively. Initial codes were assigned to segments of text representing specific themes, such as the types of AI technologies used, pedagogical approaches, benefits for teacher education, and challenges faced.
- *Code Refinement and Categorization:* Codes were continuously refined and categorized into broader themes to capture the essence of AI's impact on mathematics teacher education. This iterative process allowed for the modification and merging of codes as new patterns emerged.
- *Thematic Analysis:* Thematic analysis was conducted to identify significant themes across the research literature. MAXQDA's visual tools, such as code matrices and frequency charts, facilitated the identification of prevalent themes and sub-themes.
- *Synthesis of Findings:* The final step involved synthesizing the findings to provide a comprehensive overview of the current state of AI in pre-service and in-service mathematics teacher education. This synthesis included discussing the implications of the identified themes and suggesting areas for future

research.

Findings

The qualitative analysis of the research literature on mathematics teacher education yielded significant findings. Table 1 gives the themes and sub-themes, along with the number of references and actual references.

Table 1. The Findings of the Qualitative Analysis of the Research Literature on Mathematics Teacher Education given in Themes, Sub-themes, Number of References, Actual References, and Main Findings

Theme	Sub-Theme	Number of References	Actual References
Integration of Artificial Intelligence in Mathematics Education	Roles and Trends in AI Mathematics Education	3	Hwang & Tu, 2021; Park & Kwon, 2023; Lopez-Caudana et al., 2020
	Enhancing Mathematical Learning through AI	4	Voskoglou & Salem, 2020; Hidayat et al., 2022; Deo et al., 2020; Lee et al., 2021
	Future Directions of AI in Mathematics Education	3	Gadanidis, 2024; Yang & Bai, 2020; Sadiku et al., 2021
Integration of Artificial Intelligence in Mathematics Teacher Education	Enhancing Learning and Teaching Skills	3	Badiee & Kaufman, 2015; Bradley & Kendall, 2014; Erdemir & İngeç, 2016
	Addressing Challenges and Promoting Skill Development	9	McGarr, 2020; Pendergast et al., 2022; Wibowo et al., 2022; Kong et al., 2017; Passig, 2011; Grádaigh et al., 2021; Hudson et al., 2019; Liang, 2015; Muir et al., 2013
	Supporting Professional Development and Classroom Practices	5	Yau et al., 2022; Holstein & Aleven, 2022; Lin et al., 2022; Lee & Perret, 2022; Kim et al., 2022
	Enhancing Teacher Preparedness and Effectiveness	4	Ng et al., 2023; Gupta & Bhaskar, 2020; Hidayat et al., 2022; Kay, 2006
	Transformative Potential of AI in Teacher Education	2	Orhani, 2021; Xi, 2023
AI-Based Pedagogical Tools in Mathematics	Enhancing Teaching and Learning	2	Dai, 2023; Baumert et al., 2010

Theme	Sub-Theme	Number of References	Actual References
Education	Experiences		
	Continuous Professional Development with AI Tools	1	: Ndihokubwayo et al., 2022
	Revolutionizing Mathematics Education with AI	2	Zawacki-Richter et al., 2019; Hwang & Tu, 2021
Data-Driven Decision-Making in Mathematics Education	Utilizing AI for Analyzing Student Performance	1	Harry, 2023
	Advanced Workshops and AI-Powered Analytics	1	Wang & Han, 2020
	AI Algorithms and Dynamic Learning Environments	2	Lin, 2022; Liu et al., 2022
Adaptive Learning Systems in Mathematics Education	Tailored Instruction Through AI	2	Wang et al., 2020; Dorça, 2015
	Optimizing Classroom Instruction	2	Vainshtein et al., 2019; El-Sabagh, 2021
	Personalized Learning Experiences	4	Díez-Fonnegra & Losada, 2022; Vainshteina et al., 2018; Peng et al., 2019; Hidayat et al., 2022
AI-Enabled Assessment Tools in Mathematics Education	Enhancing Learning and Assessment Processes	4	Fu et al., 2020; Boscardin, 2023; Zhai & Nehm, 2023; Gadanidis, 2017
	Streamlining Evaluation Processes	3	Funes, 2024; Jain et al., 2022; Li et al., 2023
	Enhancing Feedback Mechanisms	3	Roh & Lee, 2023; Soesanto et al., 2022; Greenwald et al., 2021
	Impact of AI on Mathematics Education Assessment	10	Fu et al., 2020; Boscardin, 2023; Zhai & Nehm, 2023; Gadanidis, 2017; Funes, 2024; Jain et al., 2022; Li et al., 2023; Roh & Lee, 2023; Soesanto et al., 2022; Greenwald et al., 2021
Enhancing Collaborative	Facilitating Pre-	2	Jiao et al., 2022; Kuleto et al., 2021

Theme	Sub-Theme	Number of References	Actual References
Learning in Mathematics Education through AI Technologies	Service Collaborative Learning Experiences		
	Promoting In-Service Collaboration Through AI Technologies	2	Ouyang et al., 2023; Teo et al., 2022
	Strengthening Collaborative Learning through AI	2	Chen et al., 2023; Järvelä et al., 2023
Benefits, Challenges, and Ethical Considerations Regarding AI in Mathematics Education	Enhancing Teaching and Learning	3	Ng et al., 2023; Gupta & Bhaskar, 2020; Hidayat et al., 2022
	Fostering Collaboration and Knowledge Sharing	2	Jiao et al., 2022; Kuleto et al., 2021
	Navigating Ethical and Privacy Concerns	5	Damşa, 2014; Langer-Osuna, 2018; Akgün & Greenhow, 2021; Polak et al., 2022; Xu & Ouyang, 2022
	Addressing the Implementation Challenges	9	: Kay, 2006; Ertl et al., 2020; Zhang, 2023; Kasneci et al., 2023; Borenstein & Howard, 2020; Harry, 2023; Lainjo & Tsmouche, 2023; Mahligawati, 2023; Zawacki-Richter et al., 2019

Integration of Artificial Intelligence in Mathematics Education

Integrating AI into educational contexts, focusing on mathematics education, encompasses a multifaceted exploration of its applications, implications, challenges, and future directions. This comprehensive analysis draws upon various studies to understand how AI transforms teaching and learning practices in mathematics, considering ethical considerations, pedagogical strategies, and educators' perspectives.

- *Roles and Trends in AI Mathematics Education:* The intersection of AI and mathematics education has received increased research attention. Hwang and Tu (2021) and other studies have explored the roles of AI in mathematics education, emphasizing research trends and the potential for AI to transform teaching and learning practices. Park & Kwon (2023) and Lopez-Caudana et al. (2020) have examined implementing AI education in middle school and using robotics to promote active learning in mathematics, respectively.
- *Enhancing Mathematical Learning through AI:* The use of AI in mathematics education has demonstrated benefits in student engagement, personalized learning experiences, and problem-solving skills. Studies by Voskoglou & Salem (2020), Hidayat et al. (2022), and Deo et al. (2020) showcase various AI applications, from robotics to learning analytics, and their positive impact on mathematical

learning outcomes. Lee et al. (2021) further discuss AI-infused learning strategies that connect AI concepts to high school math, enhancing students' understanding of mathematical concepts.

- *Future Directions of AI in Mathematics Education:* Current research focuses on improving educational methodologies and outcomes through AI by exploring the intersections between mathematics and AI. Gadanidis (2024) and Yang & Bai (2020) emphasize the importance of continuously improving AI-based learning methods and integrating AI to enhance traditional learning approaches. The application of AI in mathematics education is seen as a revolutionary step towards personalized and flexible learning experiences, according to Sadiku et al. (2021).

Integration of Artificial Intelligence in Mathematics Teacher Education

Integrating AI technologies within mathematics teacher education encompasses two critical phases: pre-service and in-service teacher education. These phases highlight the transformative potential of AI applications in enhancing teaching practices, improving teacher preparedness, and ultimately enriching students' learning experiences in mathematics education. Below, we explore AI's applications, benefits, challenges, and future directions in these two distinct but interconnected phases.

- *Enhancing Learning and Teaching Skills:* Virtual simulations provide a safe space for pre-service teachers to practice and refine teaching skills, offering opportunities for repeated trials and practical experience application (Badiee & Kaufman, 2015; Bradley & Kendall, 2014). Intelligent tutoring systems support learning by providing personalized feedback and guidance, enhancing teaching practices and educators' innovation awareness (Erdemir & İngeç, 2016).
- *Addressing Challenges and Promoting Skill Development:* AI technologies have positively impacted pre-service teachers' behavior, classroom management skills, self-efficacy, and the development of 21st-century skills such as creativity and problem-solving (McGarr, 2020; Pendergast et al., 2022; Wibowo et al., 2022). They also enhance teacher preparedness for risks and awareness of students' cognitive experiences (Kong et al., 2017; Passig, 2011). During the COVID-19 pandemic, simulated environments and mixed-reality simulations enabled remote observation and practice, overcoming physical limitations (Grádaigh et al., 2021; Hudson et al., 2019).
- *Supporting Professional Development and Classroom Practices:* The design for human-AI complementarity, perceptions of teaching sustainable AI, and preparing teachers to integrate AI into STEM classrooms are critical for effective AI education (Yau et al., 2022; Holstein & Aleven, 2022; Lin et al., 2022; Lee & Perret, 2022). Collaborative learning designs and sustainable curriculum planning for AI education enhance in-service teachers' skills and knowledge (Kim et al., 2022; Lee & Perret, 2022).
- *Enhancing Teacher Preparedness and Effectiveness:* Educators proficient in AI transform teaching practices, improving management efficiency and decision-making (Ng et al., 2023). AI integration tailors teaching methods to students' learning styles and progress, enhancing communication and educational experiences (Gupta & Bhaskar, 2020; Hidayat et al., 2022). Challenges remain in equipping teachers with the necessary skills for effective technology use, highlighting the need for enhanced teacher education programs (Kay, 2006).

- *Transformative Potential of AI in Teacher Education:* AI technologies offer personalized guidance, feedback, and support, significantly impacting teacher-student interactions and learning outcomes (Orhani, 2021). AI-based training and assessment methods enhance teaching effectiveness and professionalism (Xi, 2023).

AI-Based Pedagogical Tools in Mathematics Education

Integrating AI-based pedagogical tools in mathematics education signifies a transformative shift towards enhancing teaching and learning processes. This shift is evident across different stages of teacher education, namely pre-service and in-service training. Each stage leverages AI to address distinct challenges and objectives, ultimately contributing to more personalized, interactive, and effective mathematics education.

- *Enhancing Teaching and Learning Experiences:* AI-driven educational software and apps are increasingly prominent in pre-service education to enhance mathematics teaching and learning experiences (Dai, 2023). These tools provide interactive and personalized learning experiences, crucial for practical instruction and student progress in secondary-level mathematics (Baumert et al., 2010). Additionally, analogy-based pedagogy, as opposed to conventional direct instruction, is supported in AI education, offering an alternative approach that may foster more profound understanding and engagement among students (Dai, 2023).
- *Continuous Professional Development with AI Tools:* For in-service teachers, it is crucial to continuously develop their abilities to integrate AI tools into existing mathematics curricula successfully. This involves evaluating and adapting AI-based resources to meet the diverse needs of their classrooms (Ndihokubwayo et al., 2022). Innovative tools like the Lesson Plan Analysis Protocol (LPAP) assist teachers in developing the pedagogical content knowledge necessary to address the educational needs of culturally and linguistically diverse student populations (Ndihokubwayo et al., 2022).
- *Revolutionizing Mathematics Education with AI*: A systematic review by Zawacki-Richter et al. (2019) emphasizes the importance of personalization in educational technology, aligning with the broader trend of technological advancements in education. Furthermore, bibliometric mapping analysis and systematic review conducted by Hwang and Tu (2021) explore AI's role and research trends in mathematics education, providing valuable insights into how AI integration reshapes teaching practices.

Data-Driven Decision-Making in Mathematics Education

The application of data-driven decision-making in mathematics education is a pivotal aspect that influences pre-service and in-service teacher training. This approach, significantly bolstered by AI, provides a strategic framework for enhancing educational practices and student learning outcomes through meticulous data analysis and application.

- *Utilizing AI for Analyzing Student Performance:* AI in pre-service education for analyzing student performance data is crucial for effectively identifying learning gaps (Harry, 2023). Educators gain insights into students' needs through this analysis, allowing for customizing teaching strategies. This approach promotes a more personalized and targeted instruction methodology, enhancing teaching practices' efficiency and effectiveness and ultimately benefiting student learning outcomes (Harry, 2023).

- *Advanced Workshops and AI-Powered Analytics:* For in-service teachers, participating in advanced workshops is crucial for learning how to interpret and act on insights derived from AI-powered analytics tools (Wang & Han, 2020). These workshops equip educators with the essential skills to make informed decisions based on data analysis. This enables more effective addressing of student needs and enhances instructional practices. Furthermore, strategies for integrating AI into ongoing assessment and feedback processes are pivotal for improving education delivery quality and fostering continuous enhancement in teaching methodologies (Wang & Han, 2020).
- *AI Algorithms and Dynamic Learning Environments:* Employing AI algorithms to analyze student work and provide immediate feedback creates a more dynamic and responsive learning environment (Lin, 2022). Additionally, using AI assistants in deep learning transforms teaching practices for teachers and students. This introduces innovative teaching models that leverage AI technology to optimize teaching and learning experiences (Liu et al., 2022).

Adaptive Learning Systems in Mathematics Education

The utilization of adaptive learning systems in mathematics education represents a significant advancement facilitated by integrating AI to deliver personalized and differentiated instruction. This technology-driven approach is being implemented across various stages of teacher education, significantly transforming teaching practices to meet individual student needs more effectively and efficiently.

- *Tailored Instruction Through AI:* In pre-service education, the emphasis is on familiarizing future educators with AI-enabled adaptive learning principles. These systems are designed to adjust the content's difficulty dynamically based on each student's performance, ensuring instruction is delivered at the most appropriate level for every individual (Wang et al., 2020; Dorça, 2015).
- *Optimizing Classroom Instruction:* In-service education trains teachers to incorporate adaptive learning platforms into their classrooms. This inclusion allows for accommodating diverse student needs and learning paces. Evaluating the impact of adaptive technologies on student engagement and achievement enables educators to optimize AI use in mathematics education, thus enhancing learning outcomes (Vainshtein et al., 2019; El-Sabagh, 2021).
- *Personalized Learning Experiences:* Adaptive e-learning environments are shown to boost student engagement and learning outcomes by providing personalized instruction and reinforcing learning concepts (Díez-Fonnegra & Losada, 2022). Furthermore, these systems aim to develop mathematical thinking and problem-solving skills by tailoring learning experiences to match students' unique styles and preferences (Vainshteina et al., 2018; Peng et al., 2019). Integrating intelligent tutoring systems and adaptive learning technologies in STEM education significantly enhances the quality of mathematics instruction (Hidayat et al., 2022).

AI-Enabled Assessment Tools in Mathematics Education

Integrating AI into assessment tools significantly transforms mathematics education, offering innovative methods to evaluate and enhance student learning. This transformation spans pre-service and in-service education phases, providing educators at all levels with the tools to personalize learning experiences, streamline evaluation processes, and improve feedback mechanisms.

- *Enhancing Learning and Assessment Processes:* Teachers in pre-service education are introduced to AI-enabled tools that offer immediate feedback on students' mathematical skills, thereby improving the learning process (Fu et al., 2020). These tools streamline assessment, provide insights into student performance, and enable educators to tailor instruction to meet individual learning needs (Boscardin, 2023). Additionally, pre-service educators learn to create assessments that adapt to students' learning levels, promoting personalized learning experiences (Zhai & Nehm, 2023; Gadanidis, 2017).
- *Streamlining Evaluation Processes:* Educators in in-service training incorporate AI-based platforms for efficient and objective evaluation of student progress. These platforms automate scoring, offer detailed analytics, and support data-driven decision-making, thereby enhancing the accuracy and reliability of assessments (Funes, 2024; Jain et al., 2022; Li et al., 2023).
- *Enhancing Feedback Mechanisms:* In-service training also emphasizes using AI to improve feedback loops in mathematics education. AI-powered feedback mechanisms allow for timely and targeted feedback, fostering continuous improvement and learning (Roh & Lee, 2023; Soesanto et al., 2022; Greenwald et al., 2021).
- *Overall Impact of AI in Mathematics Education Assessment:* Integrating AI in assessment practices within mathematics education offers numerous advantages, such as personalized learning experiences, streamlined evaluation processes, and enhanced feedback mechanisms. Educators significantly improve assessment practices by adopting AI technologies, leading to better student outcomes and more engaging learning environments.

Enhancing Collaborative Learning in Mathematics Education through AI Technologies

Integrating AI technologies in mathematics education revolutionizes collaborative learning environments. This advancement facilitates more engaging, inclusive, and effective cooperative learning experiences for students, supported by AI-powered tools that promote interaction, teamwork, and knowledge sharing. Both pre-service and in-service education phases incorporate these technologies to equip educators with the skills to foster collaborative learning.

- *Facilitating Pre-Service Collaborative Learning Experiences:* Educators in pre-service training learn to use AI-powered tools to create interactive group activities that promote peer learning and teamwork (Jiao et al., 2022) and explore AI's role in supporting group projects and peer learning, gaining insights into how technology improves student collaboration and knowledge sharing (Kuleto et al., 2021).
- *Promoting In-Service Collaboration Through AI Technologies:* In-service teachers are introduced to AI-powered platforms that aid communication, resource sharing, and collaborative problem-solving (Ouyang et al., 2023). They also assess AI tools that foster a collaborative culture in mathematics

education, ensuring the effective use of technology to establish inclusive and interactive learning environments (Teo et al., 2022).

- *Strengthening Collaborative Learning through AI:* Studies highlight that collaborative learning, involving small groups in coordinated activities, is enhanced by AI-driven tools that support joint meaning-making and knowledge creation (Chen et al., 2023). AI integration in collaborative settings promotes active engagement, critical thinking, and knowledge construction among students (Järvelä et al., 2023).

Benefits, Challenges, and Ethical Considerations Regarding AI in Mathematics Education

Integrating AI in mathematics education offers many benefits and presents particular challenges. It necessitates a careful and informed approach to maximize its potential while mitigating adverse effects. This integration impacts various aspects of education, from enhancing learning experiences and teaching practices to addressing ethical considerations and data privacy concerns.

- *Enhancing Teaching and Learning:* AI technologies offer innovative approaches to learning, providing opportunities for personalized education and improving students' learning experiences. Educators proficient in AI transform teaching practices, leading to better management efficiency, decision-making processes, and tailored teaching methods (Ng et al., 2023; Gupta & Bhaskar, 2020). AI technologies also enhance teacher-student communication, increase course accessibility, and enrich students' educational experiences (Hidayat et al., 2022).
- *Fostering Collaboration and Knowledge Sharing:* AI-driven tools facilitate collaborative learning environments, supporting group activities, peer learning, and knowledge sharing among students (Jiao et al., 2022; Kuleto et al., 2021). This integration promotes active engagement, critical thinking, and knowledge construction, significantly enhancing the learning experience in mathematics education.
- *Navigating Ethical and Privacy Concerns:* Incorporating AI in education necessitates addressing ethical factors and data privacy to ensure responsible technology use. Educators must ensure AI tools are employed in ways that safeguard student privacy, promote equity, and uphold ethical standards (Damşa, 2014; Langer-Osuna, 2018; Polak et al., 2022; Xu & Ouyang, 2022).
- *Addressing the Implementation Challenges:* The digital divide, privacy issues, lack of trust, cost implications, potential biases, and the need for teacher training on AI tools are significant challenges that must be addressed (Kay, 2006; Ertl et al., 2020; Zhang, 2023; Kasneci et al., 2023; Borenstein & Howard, 2020; Harry, 2023; Lainjo & Tsmouche, 2023; Mahligawati, 2023; Zawacki-Richter et al., 2019). Ensuring equitable access to AI technologies and responsible use is crucial for maximizing the benefits of AI in education.

Discussion

Integration of Artificial Intelligence in Mathematics Education

Integrating AI into mathematics education involves exploring its applications, implications, challenges, and future directions comprehensively. AI plays a transformative role in mathematics education by enhancing teaching and learning practices, addressing ethical considerations, and refining pedagogical strategies. Hwang and Tu (2021) highlight the growing research trends in AI's application in mathematics education, underscoring its potential to revolutionize traditional methods. Park and Kwon (2023) demonstrate how AI is implemented in middle school mathematics education, promoting active learning through robotics (Lopez-Caudana et al., 2020). These studies reflect a shift towards utilizing AI to engage students, personalize learning, and develop problem-solving skills, as emphasized by Voskoglou and Salem (2020), Hidayat et al. (2022), and Deo et al. (2020). Future research by Gadanidis (2024) and Yang and Bai (2020) focuses on continuously improving AI-based learning methods to offer personalized and flexible educational experiences, indicating a revolutionary step in mathematics education (Sadiku et al., 2021).

Integration of Artificial Intelligence in Mathematics Teacher Education

The integration of AI technologies in mathematics teacher education encompasses both pre-service and in-service training, aiming to enhance teaching practices and improve teacher preparedness. Virtual simulations provide pre-service teachers with opportunities to practice and refine their skills, offering practical experience and personalized feedback (Badiee & Kaufman, 2015; Bradley & Kendall, 2014). Intelligent tutoring systems further support teaching practices by providing guidance and fostering innovation awareness among educators (Erdemir & İngeç, 2016). The impact of AI technologies on pre-service teachers extends to enhancing classroom management skills, self-efficacy, and the development of 21st-century skills, including creativity and problem-solving (McGarr, 2020; Pendergast et al., 2022; Wibowo et al., 2022). In-service education focuses on human-AI complementarity, sustainable AI teaching, and collaborative learning designs, promoting professional development and effective AI integration in STEM classrooms (Yau et al., 2022; Holstein & Aleven, 2022; Lee & Perret, 2022).

AI-Based Pedagogical Tools in Mathematics Education

AI-based pedagogical tools represent a transformative shift in enhancing mathematics teaching and learning. These tools, prominently used in pre-service education, provide interactive and personalized learning experiences crucial for student progress in mathematics (Dai, 2023). For in-service teachers, continuous development in integrating AI tools into curricula is essential, involving the evaluation and adaptation of AI resources to meet diverse classroom needs (Ndihokubwayo et al., 2022). Innovative tools such as the Lesson Plan Analysis Protocol (LPAP) help teachers develop the pedagogical content knowledge necessary for addressing the needs of culturally and linguistically diverse student populations (Ndihokubwayo et al., 2022). The importance of personalization in educational technology is emphasized in studies by Zawacki-Richter et al. (2019), Hwang and Tu (2021), which highlight how AI reshapes teaching practices and enhances the overall learning experience.

Data-Driven Decision-Making in Mathematics Education

Data-driven decision-making in mathematics education, significantly enhanced by AI, provides a strategic framework for improving educational practices and student learning outcomes. In pre-service education, AI is crucial for analyzing student performance data, identifying learning gaps, and customizing teaching strategies (Harry, 2023). For in-service teachers, participating in advanced workshops on AI-powered analytics tools is vital for interpreting data insights and making informed decisions to address student needs (Wang & Han, 2020). AI algorithms analyzing student work and providing immediate feedback create a dynamic learning environment, optimizing teaching practices (Lin, 2022). The integration of AI assistants in deep learning further transforms teaching models, enhancing both teacher and student experiences (Liu et al., 2022).

Adaptive Learning Systems in Mathematics Education

Adaptive learning systems, facilitated by AI, deliver personalized and differentiated instruction, significantly transforming mathematics education. In pre-service education, future educators are introduced to AI-enabled adaptive learning principles that adjust content difficulty based on student performance, ensuring appropriate instruction levels (Wang et al., 2020; Dorça, 2015). In-service training focuses on incorporating adaptive learning platforms to accommodate diverse student needs, evaluate their impact on engagement and achievement, and optimize AI use in classrooms (Vainshtein et al., 2019; El-Sabagh, 2021). Adaptive e-learning environments boost student engagement and learning outcomes by providing personalized instruction tailored to students' unique styles and preferences (Díez-Fonnegra & Losada, 2022; Peng et al., 2019).

AI-Enabled Assessment Tools in Mathematics Education

AI-enabled assessment tools revolutionize mathematics education by offering innovative methods to evaluate and enhance student learning. In pre-service education, these tools provide immediate feedback, streamline assessment processes, and offer insights into student performance, enabling tailored instruction (Fu et al., 2020; Boscardin, 2023). In-service training incorporates AI-based platforms for objective evaluation, detailed analytics, and data-driven decision-making, enhancing assessment accuracy and reliability (Funes, 2024; Jain et al., 2022; Li et al., 2023). AI-powered feedback mechanisms improve feedback loops, fostering continuous improvement and learning (Roh & Lee, 2023; Soesanto et al., 2022; Greenwald et al., 2021). Integrating AI in assessment practices offers personalized learning experiences, streamlined evaluation processes, and enhanced feedback, leading to better student outcomes and more engaging learning environments.

Enhancing Collaborative Learning in Mathematics Education through AI Technologies

AI technologies revolutionize collaborative learning in mathematics education, creating engaging, inclusive, and effective cooperative learning environments. Pre-service educators learn to use AI-powered tools to create interactive group activities that promote peer learning and teamwork (Jiao et al., 2022). In-service teachers utilize AI platforms to support communication, resource sharing, and collaborative problem-solving (Ouyang et al., 2023). AI-driven tools enhance collaborative learning by promoting active engagement, critical thinking, and knowledge construction among students (Chen et al., 2023; Järvelä et al., 2023). These technologies support group projects and peer learning, improving student collaboration and knowledge sharing (Kuleto et al., 2021).

Benefits, Challenges, and Ethical Considerations Regarding AI in Mathematics Education

Integrating AI in mathematics education offers significant benefits, such as personalized learning, improved teaching practices, and enhanced collaboration, but also presents challenges and ethical considerations. AI technologies transform teaching by improving management efficiency, decision-making, and personalized instruction (Ng et al., 2023; Gupta & Bhaskar, 2020). AI-driven tools facilitate collaborative learning, promoting active engagement and knowledge sharing (Jiao et al., 2022; Kuleto et al., 2021). Ethical considerations and data privacy are crucial in responsibly using AI in education, ensuring that AI tools promote equity and safeguard student privacy (Damşa, 2014; Langer-Osuna, 2018; Akgün & Greenhow, 2021; Polak et al., 2022; Xu & Ouyang, 2022). Challenges include the digital divide, privacy issues, cost implications, potential biases, and the need for teacher training on AI tools, highlighting the importance of equitable access and responsible technology use (Kay, 2006; Ertl et al., 2020; Zhang, 2023; Kasneci et al., 2023; Borenstein & Howard, 2020; Harry, 2023; Lainjo & Tsmouche, 2023; Mahligawati, 2023; Zawacki-Richter et al., 2019).

Implications for Policy and Practice

Several vital recommendations were drawn from the relevant literature to effectively integrate AI into pre-service and in-service mathematics teacher education programs. Firstly, it is crucial to address mathematics anxiety among pre-service teachers (Gresham, 2007; Boyd et al., 2014). Teacher education programs create a more conducive environment for learning and teaching mathematics by acknowledging and mitigating anxiety. Additionally, integrating technology, such as AI, into teacher education programs positively influences pre-service teachers' attitudes and enhances their understanding of integrated teaching methods (Çorlu et al., 2015; Eshetu et al., 2023).

Furthermore, it is essential to focus on enhancing pre-service teachers' subject knowledge in mathematics (Ekstam et al., 2017; Li & Guo, 2019). Strengthening subject knowledge boosts teacher efficacy and improves the quality of mathematics education delivered to students. Programs should also emphasize developing problem-posing skills and conceptual knowledge related to basic mathematical concepts and operations (Özgen, 2019; Aksu et al., 2022).

Moreover, research-based learning approaches significantly improve pre-service teachers' research and academic writing skills, essential in modern educational settings (Prahmana, 2017; Prahmana & Kusumah, 2016). By incorporating assessment into mathematics content courses, teacher education programs ensure that pre-service teachers have a solid conceptual understanding of mathematical knowledge and problem-solving skills (Ma et al., 2008).

Lastly, to facilitate the integration of AI into mathematics education, teacher training programs should consider the affordances and challenges encountered in preparing teachers for this integration (Lee & Perret, 2022). Understanding AI methods' practical implications and limitations in STEM classrooms is crucial for effectively incorporating these technologies into teaching practices.

In conclusion, pre-service and in-service mathematics teacher education programs better prepare educators to leverage AI technologies in teaching mathematics effectively by addressing mathematics anxiety, enhancing subject knowledge, promoting problem-posing skills, incorporating research-based learning approaches, and considering the affordances of AI integration.

Future Research Directions

Further research is crucial to explore the longitudinal impact of AI on teacher practices and student outcomes. Longitudinal studies are essential to understand how AI systems influence learner-instructor interaction, teacher judgment on student learning, and the development of AI literacy among teachers (Seo et al., 2021; DeLuca et al., 2012; Zhao et al., 2022). These studies underscore the importance of tracking the enduring effects of AI implementation in education, including changes in teaching practices, confidence in assessment, and the effectiveness of AI literacy programs.

Moreover, investigating the effectiveness of AI tools, such as chatbots, in enhancing student learning outcomes requires further examination through meta-analyses and empirical studies (Wu & Yu, 2023). Understanding the mechanisms underlying AI chatbots' impact on student learning offers valuable insights for educational practitioners.

Additionally, exploring teachers' perceptions of AI as a supportive tool in education and addressing ethical challenges related to AI implementation in K-12 settings are critical areas for future research (Chounta et al., 2021; Akgün & Greenhow, 2021). Research gaps exist in developing K-12 teachers' instructional practices concerning AI and ethics, emphasizing the need for more in-depth studies.

Furthermore, investigating the integration of AI in classrooms, teacher education, and the development of adaptive AI systems improves teaching practices and student outcomes (Zhai & Nehm, 2023; Kim et al., 2022). Understanding how AI facilitates student-AI collaboration and the effects of different levels of teacher support on students' AI knowledge are also essential research avenues (Wu & Yang, 2022; Kim & Lee, 2022).

In conclusion, longitudinal studies focusing on AI's impact on teacher practices and student outcomes are vital for advancing our understanding of AI in education. By addressing these research gaps, educators and policymakers can effectively make informed decisions about integrating AI technologies into teaching and learning environments.

Conclusion

Summary of Key Insights

Synthesizing the findings of this extensive research on the impact of AI in mathematics teacher education, it is evident that AI technologies offer the transformative potential to revolutionize teaching practices, facilitate personalized learning experiences, and enhance educational outcomes. This qualitative review, grounded in a comprehensive qualitative analysis of cutting-edge research literature, has highlighted the multifaceted role of AI in redefining the landscape of mathematics teacher education for both pre-service and in-service phases.

The theoretical underpinnings of AI's impact on teacher education stand upon frameworks such as Technological Pedagogical Content Knowledge (TPACK) and Constructivism. These perspectives provide a foundation for understanding how AI is integrated into teaching practices in a manner that promotes active, student-centered learning and the construction of knowledge through meaningful experiences.

The integration of AI technologies in mathematics education has been shown to augment pedagogical strategies, enabling educators to tailor learning paths to individual student's needs, thus fostering improved engagement and achievement. Virtual simulations, intelligent tutoring systems, and personalized learning environments stand out as significant applications of AI that enrich mathematics teacher education. These technologies enhance instructional methods and offer valuable tools for addressing diverse learning preferences and challenges, such as mathematics anxiety among pre-service teachers.

However, the advent of AI in education is accompanied by considerable challenges, including the digital divide, privacy concerns, and the imperative for teacher professional development on AI utilization. The review underscores the importance of equipping educators with the necessary skills and knowledge to harness AI technologies effectively, advocating for a balanced approach that considers both the benefits and potential drawbacks of AI integration.

The review has identified several avenues for future research, emphasizing the need for longitudinal studies to ascertain AI's long-term effects on teaching and learning in mathematics education. Moreover, it calls for further exploration into the ethical dimensions of AI in education, including issues related to data privacy, equity, and the responsible use of AI technologies.

In conclusion, integrating AI into mathematics teacher education presents a promising yet complex landscape, significantly enhancing educational practices and outcomes. By addressing the identified challenges and building on the insights provided by current research, stakeholders in the field of education leverage AI technologies to foster innovative and effective teaching and learning environments. This endeavor requires a concerted effort from educators, policymakers, and researchers to ensure that AI is used ethically and effectively, ultimately contributing to advancing mathematics education in the digital age.

Limitations

While this study provides valuable insights into the integration of AI in mathematics teacher education, it is essential to acknowledge its limitations. These limitations include:

- *Scope of Literature:* The review is limited to literature published in English and does not fully capture the global perspective on AI integration in mathematics teacher education.

- *Publication Bias:* The focus on peer-reviewed articles, book chapters, and conference proceedings potentially exclude relevant studies from non-peer-reviewed sources, potentially leading to publication bias.
- *Rapid Technological Changes:* The fast-paced advancements in AI technologies mean that several findings become outdated quickly, necessitating continuous updates to the research.
- *Geographical Limitations:* The study does not adequately represent the diversity of educational contexts globally, as it primarily includes studies from certain regions.
- *Ethical and Privacy Concerns:* The ethical and privacy issues surrounding AI use in education are complex and evolving, which limit the generalizability of the findings across different educational systems and cultural settings.

References

Abdal-Haqq, I. (1998). *Constructivism in teacher education: considerations for those who would link practice to theory*. ERIC Digest. https://doi.org/10.1037/e587642011-001

Akgün, S. & Greenhow, C. (2021). Artificial intelligence in education: addressing ethical challenges in K-12 settings. *AI And Ethics, 2*(3), 431-440. https://doi.org/10.1007/s43681-021-00096-7

Aksu, Z., Kalaç, S., Özkaya, M., & Konyalioğlu, A. (2022). Pre-service mathematics teachers' conceptual knowledge related to basic concepts and operations. *Research On Education and Psychology, 6*(2), 283-297. https://doi.org/10.54535/rep.1204295

Al Kanaan, H. (2022). Awareness regarding the implication of artificial intelligence in science education among pre-service science teachers. *International Journal of Instruction, 15*(3), 895-912. https://doi.org/10.29333/iji.2022.15348a

Ashok, M., Madan, R., Joha, A., & Sivarajah, U. (2022). Ethical framework for artificial intelligence and digital technologies. *International Journal of Information Management, 62,* 102433. https://doi.org/10.1016/j.ijinfomgt.2021.102433

Badiee, F. & Kaufman, D. (2015). Design evaluation of a simulation for teacher education. *Sage Open, 5*(2), 215824401559245. https://doi.org/10.1177/2158244015592454

Baker, C. & Galanti, T. (2017). Integrating stem in elementary classrooms using model-eliciting activities: responsive, professional development for mathematics coaches and teachers. *International Journal of Stem Education, 4*(1). https://doi.org/10.1186/s40594-017-0066-3

Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., … & Tsai, Y. (2010). Teachers' mathematical knowledge, cognitive activation in the classroom, and student progress. *American Educational Research Journal, 47*(1), 133-180. https://doi.org/10.3102/0002831209345157

Berlin, D. & White, A. (2012). A longitudinal look at attitudes and perceptions related to the integration of mathematics, science, and technology education. *School Science and Mathematics, 112*(1), 20–30. https://doi.org/10.1111/j.1949-8594.2011.00111.x

Bertolini, R., Finch, S., & Nehm, R. (2023). An application of Bayesian inference to examine student retention and attrition in the stem classroom. *Frontiers In Education, 8.* https://doi.org/10.3389/feduc.2023.1073829

Borba, M. (2021). The future of mathematics education since COVID-19: humans-with-media or humans-with-non-living-things. *Educational Studies in Mathematics, 108*(1-2), 385–400. https://doi.org/10.1007/s10649-021-10043-2

Borenstein, J. & Howard, A. (2020). Emerging challenges in AI and the need for AI ethics education. *AI and Ethics,* 1(1), 61-65. https://doi.org/10.1007/s43681-020-00002-7

Boscardin, C. (2023). ChatGpt and generative artificial intelligence for medical education: potential impact and opportunity. *Academic Medicine, 99*(1), 22-27. https://doi.org/10.1097/acm.0000000000005439

Boyd, W., Foster, A., Smith, J., & Boyd, W. (2014). Feeling good about teaching mathematics: addressing anxiety amongst pre-service teachers. *Creative Education, 05*(04), 207–217. https://doi.org/10.4236/ce.2014.54030

Bradley, E. & Kendall, B. (2014). A review of computer simulations in teacher education. *Journal of Educational Technology Systems, 43*(1), 3–12. https://doi.org/10.2190/et.43.1.b

Bray, A. & Tangney, B. (2017). Technology usage in mathematics education research – a systematic review of recent trends. *Computers & Education, 114,* 255–273. https://doi.org/10.1016/j.compedu.2017.07.004

Bretscher, N. (2021). Challenging assumptions about relationships between mathematics pedagogy and ICT integration: surveying teachers in English secondary schools. *Research in Mathematics Education, 23*(2), 142-158. https://doi.org/10.1080/14794802.2020.1830156

Buckley, S., Reid, K., Goos, M., Lipp, O., & Thomson, S. (2016). Understanding and addressing mathematics anxiety using perspectives from education, psychology, and neuroscience. *Australian Journal of Education, 60*(2), 157–170. https://doi.org/10.1177/0004944116653000

Chan, K. & Zary, N. (2019). Applications and challenges of implementing artificial intelligence in medical education: integrative review. *Jmir Medical Education, 5*(1), e13930. https://doi.org/10.2196/13930

Chaudhry, M., Cukurova, M., & Luckin, R. (2022). A transparency index framework for AI in education. https://doi.org/10.35542/osf.io/bstcf

Chen, A., Yang, T., Ma, J., & Lu, Y. (2023). Employees' learning behavior in the context of AI collaboration: a perspective on the job demand-control model. *Industrial Management & Data Systems, 123*(8), 2169-2193. https://doi.org/10.1108/imds-04-2022-0221

Cheng, C., Chen, C., Fu, C., Chaou, C., Wu, Y., Hsu, C., … & Liao, C. (2020). Artificial intelligence-based education assists medical students' interpretation of hip fracture. *Insights Into Imaging, 11*(1). https://doi.org/10.1186/s13244-020-00932-0

Chiu, T. & Chai, C. (2020). Sustainable curriculum planning for artificial intelligence education: a self-determination theory perspective. *Sustainability, 12*(14), 5568. https://doi.org/10.3390/su12145568

Chou, C., Shen, T., Shen, T., & Shen, C. (2022). The level of perceived efficacy from teachers to access ai-based teaching applications. *Research and Practice in Technology Enhanced Learning, 18,* 021. https://doi.org/10.58459/rptel.2023.18021

Chounta, I., Bardone, E., Raudsep, A., & Pedaste, M. (2021). Exploring teachers' perceptions of artificial intelligence as a tool to support their practice in Estonian k-12 education. *International Journal of Artificial Intelligence in Education, 32*(3), 725–755. https://doi.org/10.1007/s40593-021-00243-5

Chuaungo, M., V.L.Nunhlimi, A., & Mishra, L. (2022). Integrating technology with constructivist pedagogy. *International Journal of Engineering Technology and Management Sciences,* 104-109.

https://doi.org/10.46647/ijetms.2022.v06i05.014

Çorlu, M., Capraro, R., & Çorlu, M. (2015). Investigating the mental readiness of pre-service teachers for integrated teaching. *International Online Journal of Educational Sciences*. https://doi.org/10.15345/iojes.2015.01.002

Cox, A. (2022). The ethics of AI for information professionals: eight scenarios. *Journal of the Australian Library and Information Association, 71*(3), 201–214. https://doi.org/10.1080/24750158.2022.2084885

Crompton, H. & Song, D. (2021). The potential of artificial intelligence in higher education. *Revista Virtual Universidad Católica Del Norte*, (62), 1-4. https://doi.org/10.35575/rvucn.n62a1

Dai, Y. (2023). Effect of an analogy-based approach of artificial intelligence pedagogy in upper primary schools. *Journal of Educational Computing Research, 61*(8), 159–186. https://doi.org/10.1177/07356331231201342

Damşa, C. (2014). The multi-layered nature of small-group learning: productive interactions in object-oriented collaboration. *International Journal of Computer-Supported Collaborative Learning,* 9(3), 247–281. https://doi.org/10.1007/s11412-014-9193-8

Davies, A., Veličković, P., Buesing, L., Blackwell, S., Zheng, D., Tomašev, N., … & Kohli, P. (2021). Advancing mathematics by guiding human intuition with AI. *Nature, 600*(7887), 70-74. https://doi.org/10.1038/s41586-021-04086-x

DeLuca, C., Chávez, T., & Cao, C. (2012). Establishing a foundation for valid teacher judgment on student learning: the role of pre-service assessment education. *Assessment in Education Principles Policy and Practice, 20*(1), 107-126. https://doi.org/10.1080/0969594x.2012.668870

Deo, R., Yaseen, Z., Al-Ansari, N., Nguyen-Huy, T., Langlands, T., & Galligan, L. (2020). Modern artificial intelligence model development for undergraduate student performance prediction: an investigation on engineering mathematics courses. *IEEE Access, 8*, 136697–136724. https://doi.org/10.1109/access.2020.3010938

Díez-Fonnegra, C. & Losada, M. (2022). The development of mathematical thinking through adaptive education: the case of a linear algebra course. *Vidya, 42*(2), 1-23. https://doi.org/10.37781/vidya.v42i2.4205

Dorça, F. (2015). Implementation and use of simulated students for test and validation of new adaptive educational systems: a practical insight. *International Journal of Artificial Intelligence in Education, 25*(3), 319–345. https://doi.org/10.1007/s40593-015-0037-0

Eguchi, A., Okada, H., & Muto, Y. (2021). Contextualizing AI education for K-12 students to enhance their learning of AI literacy through culturally responsive approaches. *KI - Künstliche Intelligenz, 35*(2), 153-161. https://doi.org/10.1007/s13218-021-00737-3

Ekstam, U., Korhonen, J., Linnanmäki, K., & Aunio, P. (2017). Special education pre-service teachers' interest, subject knowledge, and teacher efficacy beliefs in mathematics. *Teaching and Teacher Education, 63*, 338-345. https://doi.org/10.1016/j.tate.2017.01.009

El-Sabagh, H. (2021). Adaptive e-learning environment based on learning styles and its impact on development students' engagement. *International Journal of Educational Technology in Higher Education*, *18*(1). https://doi.org/10.1186/s41239-021-00289-4

Erdemir, M. & İngeç, Ş. (2016). Investigating pre-service mathematics teachers' innovation awareness and views regarding intelligent tutoring systems. *Universal Journal of Educational Research, 4*(12), 2783-2794. https://doi.org/10.13189/ujer.2016.041212

Ertl, B., Csanadi, A., & Tarnai, C. (2020). Getting closer to the digital divide: An analysis of impacts on digital competencies based on the German PIAAC sample. *International Journal of Educational Development, 78*, 102259. https://doi.org/10.1016/j.ijedudev.2020.102259

Escorcia, I., Acevedo-Rincón, J., & Navarro, M. (2023). Specialized knowledge of the mathematics teacher to teach through modeling using ICTS. *Acta Scientiae, 25*(1), 160-195. https://doi.org/10.17648/acta.scientiae.7363

Eshetu, D., Atnafu, M., & Woldemichael, M. (2023). Technology integrated guided inquiry-based learning approach and pre-service mathematics teachers' attitude towards learning geometry. *Mediterranean Journal of Social & Behavioral Research, 7*(1), 3–13. https://doi.org/10.30935/mjosbr/12560

Firat, M. (2023). What ChatGpt means for universities: perceptions of scholars and students. *Journal of Applied Learning & Teaching, 6*(1). https://doi.org/10.37074/jalt.2023.6.1.22

Fu, S., Gu, H., & Yang, B. (2020). The affordances of AI-enabled automatic scoring applications on learners' continuous learning intention: an empirical study in China. *British Journal of Educational Technology, 51*(5), 1674-1692. https://doi.org/10.1111/bjet.12995

Funes, J. (2024). Description of parameter variation learning with artificial intelligence and GeoGebra in students of a differential equations course. *Journal of Physics Conference Series, 2701*(1), 012049. https://doi.org/10.1088/1742-6596/2701/1/012049

Gadanidis, G. (2017). Artificial intelligence, computational thinking, and mathematics education. *International Journal of Information and Learning Technology, 34*(2), 133-139. https://doi.org/10.1108/ijilt-09-2016-0048

Gadanidis, G. (2024). Mathematics and artificial intelligence: Intersections and educational implications. *Journal of Digital Life and Learning, 4*(1), 1-24. https://doi.org/10.51357/jdll.v4i1.249

Grádaigh, S., Connolly, C., Mahon, B., Agnew, A., & Poole, W. (2021). An investigation of emergency virtual observation (EVO) in initial teacher education in Australia and Ireland during the COVID-19 pandemic. *Irish Educational Studies, 40*(2), 303–310. https://doi.org/10.1080/03323315.2021.1916561

Greenwald, E., Leitner, M., & Wang, N. (2021). Learning artificial intelligence: insights into how youth encounter and build understanding of AI concepts. *Proceedings of the AAAI Conference on Artificial Intelligence, 35*(17), 15526-15533. https://doi.org/10.1609/aaai.v35i17.17828

Gresham, G. (2007). A study of mathematics anxiety in pre-service teachers. *Early Childhood Education Journal, 35*(2), 181–188. https://doi.org/10.1007/s10643-007-0174-7

Gupta, K. & Bhaskar, P. (2020). Inhibiting and motivating factors influencing teachers' adoption of AI-based teaching and learning solutions: prioritization using analytic hierarchy process. *Journal of Information Technology Education Research, 19*, 693–723. https://doi.org/10.28945/4640

Hannan, E. (2021). Ai: new source of competitiveness in higher education. Competitiveness Review. *International Business Journal Incorporating Journal of Global Competitiveness, 33*(2), 265–279. https://doi.org/10.1108/cr-03-2021-0045

Harry, A. (2023). Role of AI in education. *Interdisciplinary Journal and Humanity (Injurity), 2*(3), 260–268. https://doi.org/10.58631/injurity.v2i3.52

Henry, J. & Oliver, M. (2021). Who will watch the Watchmen? The ethico-political arrangements of algorithmic proctoring for academic integrity. *Postdigital Science and Education, 4(*2), 330–353. https://doi.org/10.1007/s42438-021-00273-1

Hidayat, R., Mohamed, M., Suhaizi, N., Sabri, N., Mahmud, M., & Baharuddin, S. (2022). Artificial intelligence in mathematics education: a systematic literature review. *International Electronic Journal of Mathematics Education, 17*(3), em0694. https://doi.org/10.29333/iejme/12132

Holstein, K. & Aleven, V. (2022). Designing for human–ai complementarity in k-12 education. *AI Magazine, 43*(2), 239-248. https://doi.org/10.1002/aaai.12058

How, M. & Hung, D. (2019). Educing ai-thinking in science, technology, engineering, arts, and mathematics (steam) education. *Education Sciences,* 9(3), 184. https://doi.org/10.3390/educsci9030184

How, M. & Hung, D. (2019). Educing ai-thinking in science, technology, engineering, arts, and mathematics (steam) education. *Education Sciences*, *9*(3), 184. https://doi.org/10.3390/educsci9030184

Hudson, M., Voytecki, K., Owens, T., & Zhang, G. (2019). Preservice teacher experiences implementing classroom management practices through mixed-reality simulations. *Rural Special Education Quarterly, 38*(2), 79–94. https://doi.org/10.1177/8756870519841421

Hwang, G. & Tu, Y. (2021). Roles and research trends of artificial intelligence in mathematics education: a bibliometric mapping analysis and systematic review. *Mathematics*, *9*(6), 584. https://doi.org/10.3390/math9060584

Jain, R., Garg, N., & Khera, S. (2022). Adoption of AI-enabled tools in social development organizations in India: an extension of UTAUT model. *Frontiers in Psychology, 13.* https://doi.org/10.3389/fpsyg.2022.893691

Järvelä, S., Nguyen, A., & Hadwin, A. (2023). Human and artificial intelligence collaboration for socially shared regulation in learning. *British Journal of Educational Technology, 54*(5), 1057-1076. https://doi.org/10.1111/bjet.13325

Javed, R., Nasir, O., Borit, M., Vanhée, L., Zea, E., Gupta, S., … & Qadir, J. (2022). Get out of the bag! Silos in AI ethics education: unsupervised topic modeling analysis of global AI curricula. *Journal of Artificial Intelligence Research, 73*, 933–965. https://doi.org/10.1613/jair.1.13550

Jiao, P., Ouyang, F., Zhang, Q., & Alavi, A. (2022). Artificial intelligence-enabled prediction model of student academic performance in online engineering education. *Artificial Intelligence Review, 55*(8), 6321-6344. https://doi.org/10.1007/s10462-022-10155-y

Jung, H., Stehr, E., & He, J. (2019). Mathematical modeling opportunities reported by secondary mathematics preservice teachers and instructors. *School Science and Mathematics, 119*(6), 353-365. https://doi.org/10.1111/ssm.12359

Karataş, K. & Yilmaz, N. (2021). Evaluating prospective mathematics teachers' development of ethical knowledge and awareness. *Research in Pedagogy, 11*(2), 377-394. https://doi.org/10.5937/istrped2102377k

Kasneci, E., Seßler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F., … & Nerdel, C. (2023). ChatGpt for good? On opportunities and challenges of large language models for education. https://doi.org/10.35542/osf.io/5er8f

Kay, R. (2006). Evaluating strategies used to incorporate technology into preservice education. *Journal of*

Research on Technology in Education, *38*(4), 383–408. https://doi.org/10.1080/15391523.2006.10782466

Kim, J. & Lee, S. (2022). Are two heads better than one?: the effect of student-ai collaboration on students' learning task performance. *Techtrends*, *67*(2), 365-375. https://doi.org/10.1007/s11528-022-00788-9

Kim, J., Lee, H., & Cho, Y. (2022). Learning design to support student-ai collaboration: perspectives of leading teachers for AI in education. *Education and Information Technologies*, *27*(5), 6069–6104. https://doi.org/10.1007/s10639-021-10831-6

Kong, Y., Kayumova, L., & Zakirova, V. (2017). Simulation technologies in preparing teachers to deal with risks. *Eurasia Journal of Mathematics Science and Technology Education*, *13*(8). https://doi.org/10.12973/eurasia.2017.00962a

Koyunkaya, M. & Bozkurt, G. (2019). An examination of GeoGebra tasks designed by pre-service mathematics teachers in terms of mathematical depth and technological action. *Necatibey Eğitim Fakültesi Elektronik Fen Ve Matematik Eğitimi Dergisi, 13*(2), 515-544. https://doi.org/10.17522/balikesirnef.573521

Kuleto, V., Ilić, M., Dumangiu, M., Ranković, M., Martins, O., Păun, D., … & Mihoreanu, L. (2021). Exploring opportunities and challenges of artificial intelligence and machine learning in higher education institutions. *Sustainability*, *13*(18), 10424. https://doi.org/10.3390/su131810424

Lainjo, B. & Tsmouche, H. (2023). Impact of artificial intelligence on higher learning institutions. *International Journal of Education Teaching and Social Sciences, 3*(2), 96-113. https://doi.org/10.47747/ijets.v3i2.1028

Langer-Osuna, J. (2018). Productive disruptions: rethinking the role of off-task interactions in collaborative mathematics learning. *Education Sciences*, *8*(2), 87. https://doi.org/10.3390/educsci8020087

Lee, I. & Perret, B. (2022). Preparing high school teachers to integrate AI methods into STEM classrooms. *Proceedings of the AAAI Conference on Artificial Intelligence, 36*(11), 12783-12791. https://doi.org/10.1609/aaai.v36i11.21557

Lee, S., Mott, B., Ottenbreit-Leftwich, A., Scribner, A., Taylor, S., Park, K., … & Lester, J. (2021). Ai-infused collaborative inquiry in upper elementary school: a game-based learning approach. *Proceedings of the AAAI Conference on Artificial Intelligence*, *35*(17), 15591-15599. https://doi.org/10.1609/aaai.v35i17.17836

Li, S. & Guo, M. (2019). The research about subject knowledge of mathematics educational postgraduates. https://doi.org/10.2991/icaessr-19.2019.18

Li, T., Reigh, E., He, P., & Miller, E. (2023). Can we and should we use artificial intelligence for formative assessment in science? *Journal of Research in Science Teaching, 60*(6), 1385–1389. https://doi.org/10.1002/tea.21867

Liang, J. (2015). Live video classroom observation: an effective approach to reducing reactivity in collecting observational information for teacher professional development. *Journal of Education for Teaching International Research and Pedagogy*, *41*(3), 235–253. https://doi.org/10.1080/02607476.2015.1045314

Liang, J., Chai, C., Koh, J., Yang, C., & Tsai, C. (2013). Surveying in-service preschool teachers' technological pedagogical content knowledge. *Australasian Journal of Educational Technology*, *29*(4).

https://doi.org/10.14742/ajet.299

Lin, H. (2022). Influences of artificial intelligence in education on teaching effectiveness. *International Journal of Emerging Technologies in Learning (IJET), 17*(24), 144–156. https://doi.org/10.3991/ijet.v17i24.36037

Lin, X., Chen, L., Chan, K., Peng, S., Chen, X., Liu, J., … & Hu, Q. (2022). Teachers' perceptions of teaching sustainable artificial intelligence: a design frame perspective. *Sustainability, 14*(13), 7811. https://doi.org/10.3390/su14137811

Liu, Y., Chen, L., & Yao, Z. (2022). The application of artificial intelligence assistant to deep learning in teachers' teaching and students' learning processes. *Frontiers in Psychology, 13*. https://doi.org/10.3389/fpsyg.2022.929175

Lopez-Caudana, E., Ramírez-Montoya, M., Martínez-Pérez, S., & Rodríguez-Abitia, G. (2020). Using robotics to enhance active learning in mathematics: a multi-scenario study. *Mathematics, 8*(12), 2163. https://doi.org/10.3390/math8122163

Ma, X., Millman, R., & Wells, M. (2008). Infusing assessment into mathematics content courses for pre-service elementary school teachers. *Educational Research for Policy and Practice, 7*(3), 165–181. https://doi.org/10.1007/s10671-008-9050-5

Mahligawati, F. (2023). Artificial intelligence in physics education: a comprehensive literature review. *Journal of Physics Conference Series, 2596*(1), 012080. https://doi.org/10.1088/1742-6596/2596/1/012080

Manchulenko, L., Nosovets, N., Chorna, H., Fonariuk, O., & Turbar, T. (2021). Constructivism in the training of students of pedagogical specialties. *Laplage Em Revista, 7*(Extra-B), 57-67. https://doi.org/10.24115/s2446-622020217extra-b884p.57-67

Martín-Núñez, J., Ar, A., Fernández, R., Abbas, A., & Radovanovic, D. (2023). Does intrinsic motivation mediate the perceived artificial intelligence (AI) learning and computational thinking of students during the COVID-19 pandemic? *Computers and Education Artificial Intelligence, 4*, 100128. https://doi.org/10.1016/j.caeai.2023.100128

McGarr, O. (2020). The use of virtual simulations in teacher education to develop pre-service teachers' behavior and classroom management skills: implications for reflective practice. *Journal of Education for Teaching International Research and Pedagogy, 47*(2), 274–286. https://doi.org/10.1080/02607476.2020.1733398

Muir, T., Allen, J., Rayner, C., & Cleland, B. (2013). Preparing pre-service teachers for classroom practice in a virtual world: a pilot study using second life. *Journal of Interactive Media in Education, 2013*(1), 3. https://doi.org/10.5334/2013-03

Nazaretsky, T., Ariely, M., Cukurova, M., & Alexandron, G. (2022). Teachers' trust in AI-powered educational technology and a professional development program to improve it. *British Journal of Educational Technology, 53*(4), 914-931. https://doi.org/10.1111/bjet.13232

Ndihokubwayo, K., Byukusenge, C., Byusa, E., Habiyaremye, H., Mbonyiryivuze, A., & Mukagihana, J. (2022). Lesson plan analysis protocol (lpap): a useful tool for researchers and educational evaluators. *Heliyon, 8*(1), e08730. https://doi.org/10.1016/j.heliyon.2022.e08730

Ng, D., Leung, J., Su, J., Ng, R., & Chu, S. (2023). Teachers' AI digital competencies and twenty-first-century skills in the post-pandemic world. *Educational Technology Research and Development, 71*(1), 137-

161. https://doi.org/10.1007/s11423-023-10203-6

Nguyen, A., Ngo, H., Hong, Y., Dang, B., & Nguyen, B. (2022). Ethical principles for artificial intelligence in education. *Education and Information Technologies, 28*(4), 4221-4241. https://doi.org/10.1007/s10639-022-11316-w

Orhani, S. (2021). Inteligjenca artificiale në mësimdhënien dhe të nxënit e lëndës së matematikës. *Kosova Eğitim Araştırmaları Dergisi, 2/3*(2/3), 29-38. https://doi.org/10.29228/kerjournal.54981

Ouyang, F., Wu, M., Zheng, L., Zhang, L., & Jiao, P. (2023). Integration of artificial intelligence performance prediction and learning analytics to improve student learning in online engineering course. *International Journal of Educational Technology in Higher Education*, *20*(1). https://doi.org/10.1186/s41239-022-00372-4

Özgen, K. (2019). Problem-posing skills for mathematical literacy: the sample of teachers and pre-service teachers. *Eurasian Journal of Educational Research*, *19*(84), 1–36. https://doi.org/10.14689/ejer.2019.84.9

Padmavathi, M. (2017). Preparing teachers for technology-based teaching-learning using TPACK. I-Manager S. *Journal on School Educational Technology, 12*(3), 1. https://doi.org/10.26634/jsch.12.3.10384

Park, W. & Kwon, H. (2023). Implementing artificial intelligence education for middle school technology education in Republic of Korea. *International Journal of Technology and Design Education, 34*(1), 109–135. https://doi.org/10.1007/s10798-023-09812-2

Passig, D. (2011). The impact of immersive virtual reality on educators' awareness of the cognitive experiences of pupils with dyslexia. *Teachers College Record, 113*(1), 181–204. https://doi.org/10.1177/016146811111300105

Pendergast, D., O'Brien, M., Prestridge, S., & Exley, B. (2022). Self-efficacy in a 3-dimensional virtual reality classroom—initial teacher education students' experiences. *Education Sciences, 12*(6), 368. https://doi.org/10.3390/educsci12060368

Peng, H., Ma, S., & Spector, J. (2019). Personalized adaptive learning: an emerging pedagogical approach enabled by a smart learning environment. *Smart Learning Environments, 6*(1). https://doi.org/10.1186/s40561-019-0089-y

Polak, S., Schiavo, G., & Zancanaro, M. (2022). Teachers' perspective on artificial intelligence education: an initial investigation. https://doi.org/10.1145/3491101.3519866

Popenici, S. & Kerr, S. (2017). Exploring the impact of artificial intelligence on teaching and learning in higher education. *Research and Practice in Technology Enhanced Learning, 12*(1). https://doi.org/10.1186/s41039-017-0062-8

Prahmana, R. & Kusumah, Y. (2016). The hypothetical learning trajectory on research in mathematics education using research-based learning. *Pedagogika, 123*(3), 42-54. https://doi.org/10.15823/p.2016.32

Prahmana, R. (2017). The role of research-based learning to enhance students' research and academic writing skills. *Journal of Education and Learning (Edulearn), 11*(3), 351–366. https://doi.org/10.11591/edulearn.v11i3.5871

Pua, S., Ahmad, N., & Khambari, M. (2021). Identification and analysis of core topics in educational artificial intelligence research: a bibliometric analysis. *Cypriot Journal of Educational Sciences, 16*(3), 995-1009. https://doi.org/10.18844/cjes.v16i3.5782

Rizqi, N. & Dewi, I. (2022). Mathematics learning in the era of Society 5.0 in terms of the objectives and ideology of mathematics education. *Edutec Journal of Education and Technology*, *6*(2), 403–412. https://doi.org/10.29062/edu.v6i2.487

Roh, S. & Lee, Y. (2023). Developing culturally tailored mobile web app education to promote breast cancer screening: knowledge, barriers, and needs among American Indian women. *Journal of Cancer Education*, *38*(4), 1224–1233. https://doi.org/10.1007/s13187-022-02252-x

Sadiku, M., Ashaolu, T., Ajayi-Majebi, A., & Musa, S. (2021). Artificial intelligence in education. *International Journal of Scientific Advances*, 2(1). https://doi.org/10.51542/ijscia.v2i1.2

Seo, K., Tang, J., Roll, I., Fels, S., & Yoon, D. (2021). The impact of artificial intelligence on learner–instructor interaction in online learning. *International Journal of Educational Technology in Higher Education, 18*(1). https://doi.org/10.1186/s41239-021-00292-9

Shu, X. (2016). An action research on TPACK's influence on teachers of national open university: exemplified with an English teacher of Zhejiang radio and tv university. *Oalib, 03*(01), 1–6. https://doi.org/10.4236/oalib.1102336

Soesanto, R., Dirgantoro, K., & Priyanti, N. (2022). Indonesian students' perceptions towards AI-based learning in mathematics. *Journal on Mathematics Education, 13*(3), 531-548. https://doi.org/10.22342/jme.v13i3.pp531-548

Song, J., Zhang, L., Yu, J., Yan, P., Ma, A., & Lu, Y. (2022). Paving the way for novices: how to teach AI for k-12 education in China. *Proceedings of the AAAI Conference on Artificial Intelligence, 36*(11), 12852–12857. https://doi.org/10.1609/aaai.v36i11.21565

Sopova, D. (2022). Ethical principles of social educator activity. *The Modern Higher Education Review*, (7), 76–83. https://doi.org/10.28925/2518-7635.2022.77

Sperling, K., Stenliden, L., Nissen, J., & Heintz, F. (2022). Still w(ai)ting for the automation of teaching: an exploration of machine learning in Swedish primary education using actor-network theory. *European Journal of Education, 57*(4), 584-600. https://doi.org/10.1111/ejed.12526

Svetlova, E. (2022). AI ethics and systemic risks in finance. *AI and Ethics*, *2*(4), 713–725. https://doi.org/10.1007/s43681-021-00129-1

Tan, J. (2022). Information analysis of advanced mathematics education-adaptive algorithm based on big data. *Mathematical Problems in Engineering*, *2022*, 1–9. https://doi.org/10.1155/2022/7796681

Temel, H. & Gür, H. (2022). Opinions of elementary mathematics teacher candidates on the use of digital technologies in mathematics education. *Journal of Educational Technology and Online Learning*, *5*(4), 864-889. https://doi.org/10.31681/jetol.1151382

Teo, Z., Lee, A., Campbell, P., Chan, R., & Ting, D. (2022). Developments in artificial intelligence for ophthalmology: federated learning. *Asia-Pacific Journal of Ophthalmology*, *11*(6), 500–502. https://doi.org/10.1097/apo.0000000000000582

Timms, M. (2016). Letting artificial intelligence in education out of the box: educational cobots and smart classrooms. *International Journal of Artificial Intelligence in Education*, *26*(2), 701–712. https://doi.org/10.1007/s40593-016-0095-y

Türk, N., Kalayci, N., & Yamak, H. (2018). New trends in higher education in the globalizing world: stem in teacher education. *Universal Journal of Educational Research, 6*(6), 1286-1304.

https://doi.org/10.13189/ujer.2018.060620

Vainshtein, I. V., Shershneva, V. A., Esin, R. V., & Noskov, M. V. (2019). Individualization of education in terms of e-learning: experience and prospects. Journal of Siberian Federal University. *Humanities & Social Sciences, 9*(12), 1753-1770. https://doi.org/10.17516/1997-1370-0481

Vainshteina, Y., Shershneva, V., Есин, Р., Tsibulsky, G., & Ishchukova, E. (2018). Adaptation algorithms of mathematical educational content in e-learning courses. *SHS Web of Conferences*, *48*, 01010. https://doi.org/10.1051/shsconf/20184801010

Voskoglou, M. & Salem, A. (2020). Benefits and limitations of the artificial with respect to the traditional learning of mathematics. *Mathematics*, *8*(4), 611. https://doi.org/10.3390/math8040611

Wang, D. & Han, H. (2020). Applying learning analytics dashboards based on process-oriented feedback to improve students' learning effectiveness. *Journal of Computer Assisted Learning*, *37*(2), 487-499. https://doi.org/10.1111/jcal.12502

Wang, S., Christensen, C., Cui, W., Tong, R., Yarnall, L., Shear, L., … & Feng, M. (2020). When adaptive learning is effective learning: comparison of an adaptive learning system to teacher-led instruction. *Interactive Learning Environments, 31*(2), 793–803. https://doi.org/10.1080/10494820.2020.1808794

Wang, X., He, X., Wei, J., Liu, J., Li, Y., & Liu, X. (2023). Application of artificial intelligence to the public health education. *Frontiers in Public Health, 10*. https://doi.org/10.3389/fpubh.2022.1087174

Wibowo, F., Priane, W., Darman, D., Guntara, Y., & Ahmad, N. (2022). Dissemination of virtual microscopic simulation (VMS) to sparking in stem for facilitating 21st - century skills (21-cs). *Journal of Physics Conference Series, 2377*(1), 012074. https://doi.org/10.1088/1742-6596/2377/1/012074

Windschitl, M. (1999). A vision educators put into practice: portraying the constructivist classroom as a cultural system. *School Science and Mathematics, 99*(4), 189-196. https://doi.org/10.1111/j.1949-8594.1999.tb17473.x

Wu, R. & Yu, Z. (2023). Do AI chatbots improve students learning outcomes? Evidence from a meta-analysis. *British Journal of Educational Technology, 55*(1), 10-33. https://doi.org/10.1111/bjet.13334

Wu, S. & Yang, K. (2022). The effectiveness of teacher support for students' learning of artificial intelligence popular science activities. *Frontiers in Psychology, 13*. https://doi.org/10.3389/fpsyg.2022.868623

Xi, J. (2023). Artificial intelligence technology in the assessment of teachers' music teaching skills training. *International Journal of Educational Innovation and Science, 4*(1). https://doi.org/10.38007/ijeis.2023.040112

Xu, W. & Ouyang, F. (2022). The application of AI technologies in stem education: a systematic review from 2011 to 2021. *International Journal of Stem Education, 9*(1). https://doi.org/10.1186/s40594-022-00377-5

Yang, S. & Bai, H. (2020). The integration design of artificial intelligence and normal students' education. *Journal of Physics Conference Series, 1453*(1), 012090. https://doi.org/10.1088/1742-6596/1453/1/012090

Yau, K., Chai, C., Chiu, T., Meng, H., King, I., & Yam, Y. (2022). A phenomenographic approach on teacher conceptions of teaching artificial intelligence (AI) in k-12 schools. *Education and Information Technologies, 28*(1), 1041-1064. https://doi.org/10.1007/s10639-022-11161-x

Yu, L. & Yu, Z. (2023). Qualitative and quantitative analyses of artificial intelligence ethics in education using

Vos-Viewer and Citnet-Explorer. *Frontiers in Psychology, 14.* https://doi.org/10.3389/fpsyg.2023.1061778

Zawacki-Richter, O., Marín, V., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education – where are the educators? *International Journal of Educational Technology in Higher Education, 16*(1). https://doi.org/10.1186/s41239-019-0171-0

Zhai, X. & Nehm, R. (2023). AI and formative assessment: The train has left the station. *Journal of Research in Science Teaching, 60*(6), 1390-1398. https://doi.org/10.1002/tea.21885

Zhai, X. & Nehm, R. (2023). AI and formative assessment: The train has left the station. *Journal of Research in Science Teaching, 60*(6), 1390-1398. https://doi.org/10.1002/tea.21885

Zhang, X. (2023). The digital divide: class and equality education. *SHS Web of Conferences, 157*, 04027. https://doi.org/10.1051/shsconf/202315704027

Zhao, L., Wu, X., & Luo, H. (2022). Developing AI literacy for primary and middle school teachers in China: based on a structural equation modeling analysis. *Sustainability, 14*(21), 14549. https://doi.org/10.3390/su142114549

Zhao, X., Guo, Z., & Liu, S. (2021). Exploring key competencies and professional development of music teachers in primary schools in the era of artificial intelligence. *Scientific Programming, 2021*, 1–9. https://doi.org/10.1155/2021/5097003

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