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Artificial intelligence in STEM education: A systematic synthesis of trends, tools, and implications (2014-2025)

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ABSTRACT

The integration of artificial intelligence (AI) into science, technology, engineering, and mathematics (STEM) education has advanced rapidly over the last decade, with significant acceleration post-COVID-19. This review investigates how AI has been employed to enhance STEM teaching and learning, evaluates the dominant research methodologies used, and identifies key trends and challenges in the field between 2014 and 2024. A systematic literature review was conducted following the preferred reporting items for systematic reviews and meta-analyses protocol. An initial pool of 1,200 peer-reviewed articles was identified from databases such as Semantic Scholar, PubMed, Scopus, and Google Scholar. After rigorous screening, 30 high-quality studies were included for final analysis. Each paper was analyzed across variables such as authorship, year, educational level, AI tools used, STEM domain, country, methodology, and core findings. Post-2020 research shows a clear increase in the use of systematic reviews, meta-analyses, and empirical designs. Studies increasingly employ design-based and theoretical approaches to address AI ethics, creativity, and learner-centered interaction. AI applications most often support intelligent tutoring, automated feedback, and personalized learning strategies in secondary and higher education. The review highlights AI's transformative potential in STEM education while also emphasizing ethical, infrastructural, and pedagogical challenges. Future research should focus on inclusive and context-sensitive implementation strategies.

Keywords: artificial intelligence, STEM education, systematic literature review, computational thinking, K-12 education, digital pedagogy

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INTRODUCTION

In the evolving landscape of education, the integration of artificial intelligence (AI) into science, technology, engineering, and mathematics (STEM) education has emerged as a transformative force, offering innovative solutions for personalized learning, real-time assessment, intelligent tutoring, and data-driven instruction (Holmes et al., 2019; Luckin et al., 2016). Over the past decade—particularly post-2020—the convergence of AI and STEM pedagogy has become a focal point of global research efforts, reflecting both technological advancement and an urgent need to reimagine educational delivery in the wake of the COVID-19 pandemic (Roll & Wylie, 2016; Zawacki-Richter et al., 2019).

This systematic literature review (SLR) aims to examine key developments, methodologies, and findings from thirty peer-reviewed articles selected from a broader pool of over 1,200 studies identified through comprehensive database searches. The focus is to analyze how AI tools—ranging from machine learning and neural networks to natural language processing and intelligent agents—are applied to solve pedagogical challenges across STEM domains. Special attention is given to the diversity of methodologies employed, the level of education targeted, AI subfields utilized, STEM subdomains addressed, and the pedagogical or practical outcomes reported.

The review process was guided by the preferred reporting items for systematic reviews and meta-analyses (PRISMA) framework (Moher et al., 2009), ensuring transparency, rigor, and replicability. An initial pool of 1,200 papers was narrowed through a multi-stage process involving abstract screening, relevance filtering, and full-text assessment, resulting in a final selection of 30 high-quality studies. The inclusion criteria emphasized originality, methodological clarity, domain relevance, and recency (2014-2024), while excluding non-peer-reviewed, duplicate, or low-impact contributions.

An emerging trend within the selected corpus is the **rise in methodological sophistication**: post-2020 studies increasingly employ SLRs, meta-analyses, and mixed methods approaches (Bozkurt et al., 2021). Empirical studies dominate, particularly in evaluating the efficacy of AI tools in real classrooms, often through quasi-experimental or longitudinal designs (Chen et al., 2021; Nkambou et al., 2022). Additionally, **design-based research** and **theoretical frameworks** are gaining traction, particularly in exploring AI ethics, creativity, and cognitive engagement in STEM learning (Holmes, 2022; Spector, 2020).

The integration of AI in STEM education is not monolithic; rather, it spans a broad spectrum of applications and implications. While some studies focus on algorithmic personalization in mathematics and physics instruction, others investigate intelligent robotics for early science education or AI-based simulations for engineering and data science (Chassignol et al., 2018; Kong et al., 2021). Despite these advancements, challenges such as bias in AI systems, ethical implications, teacher readiness, and equitable access remain underexplored in many contexts—particularly in low-resource educational environments (Bond et al., 2021; Zawacki-Richter et al., 2019).

This review contributes to the growing body of meta-scholarship by mapping out how AI has been employed across STEM education from 2014 to 2024, identifying critical research gaps, and proposing directions for future inquiry. As educational systems worldwide embrace AI-driven transformation, evidence-based insights from systematic reviews like this are crucial for guiding policy, pedagogy, and technological innovation in inclusive and responsible ways.

METHODOLOGY

Purpose of the Review

This SLR aims to explore the trends, methodological patterns, and thematic evolution of research at the intersection of AI and STEM education between 2014 and 2024. The review seeks to identify emerging innovations, pedagogical practices, and empirical foundations that characterize the integration of AI within STEM domains.

Research Questions

The following research questions guided the review:

1. What are the dominant themes and domains explored in the integration of AI in STEM education?
2. What methodological approaches have been employed in studies between 2014-2024?
3. What trends can be observed in the evolution of AI tools and pedagogical practices in STEM contexts?
4. How do the selected studies address the challenges and ethical concerns in AI-STEM education?

Search Strategy

A comprehensive search was conducted across five major academic databases:

- **Scopus**
- **Web of Science**
- **Semantic Scholar**
- **Google Scholar**
- **ERIC/Education Source**

The search string used was developed through a combination of Boolean operators, keywords, and controlled vocabulary (MeSH and ERIC Thesaurus terms). Example search queries included: ("Artificial Intelligence" OR "AI") AND ("STEM Education" OR "Science Education" OR "Technology Education" OR "Engineering Education" OR "Mathematics Education") AND ("Pedagogy" OR "Teaching" OR "Learning" OR "Assessment") AND ("2014" TO "2024").

Table 1. Eligibility criteria

Inclusion criteria	Exclusion criteria
Studies published between 2014 and 2024	Articles without full text available
Focused on AI applications in any STEM subject	Studies outside the educational context
Empirical, review, or design-based studies	Non-peer-reviewed or theoretical opinion papers
English-language only	Studies not focused on AI-STEM integration

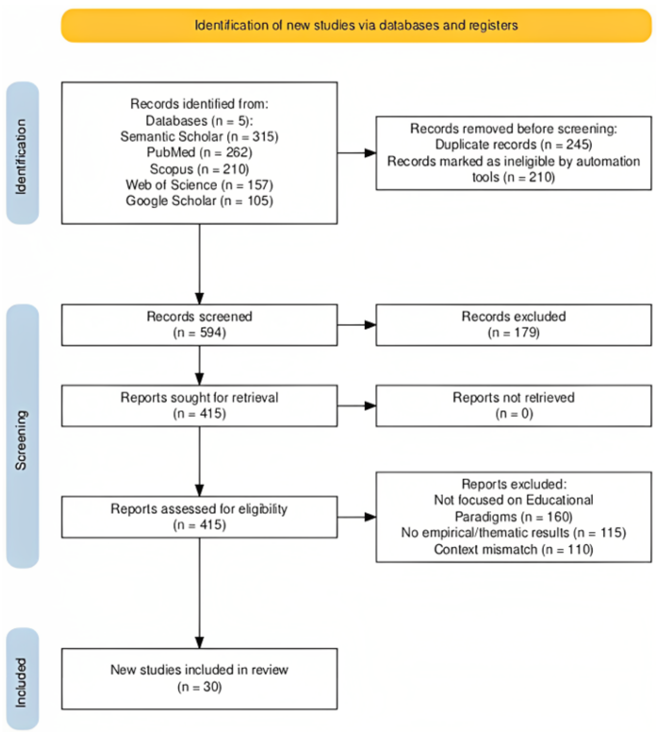

Figure 1. PRISMA 2020 flow diagram illustrating the study identification, screening, eligibility, and inclusion process for the systematic review [Source: Adapted from the PRISMA 2020 Statement (Page et al., 2021)]

Searches were limited to **peer-reviewed journal articles** published between **January 2014** and **June 2024**. Grey literature, dissertations, and conference proceedings were excluded.

Eligibility Criteria

Table 1 shows the eligibility criteria.

Screening and Selection Process

The selection process adhered to the PRISMA 2020 guidelines to ensure transparency and methodological rigor. A total of **1,049 records** were initially identified across five academic databases: Semantic Scholar (315), PubMed (262), Scopus (210), Web of Science (157), and Google Scholar (105). Following the removal of **245 duplicate entries** and **240 records eliminated for other reasons**, **564 articles** remained for title and abstract screening. Based on relevance and alignment with the review's inclusion criteria, **189 records** were excluded at this stage. The remaining **375 full-text articles** were retrieved and assessed for eligibility. After a detailed evaluation, **30 studies** met all criteria and were included in the final synthesis. The full screening and selection process is illustrated in the PRISMA 2020 flow diagram (**Figure 1**).

Table 2. AI in STEM Education (2014-2024)

Reference	Methodology	Educational level	STEM domain	AI focus	Key findings
Arifin et al. (2025)	Bibliometric review	Science education	Science	AI tools in science	AI enhances labs, simulations, personalized feedback
Sutomo and Turmudi (2025)	SLR	Math education	Math	AI for tutoring, problem-solving	Boosts interaction and motivation
Salih et al. (2024)	Integrative review	Teacher education	STEM	Ethical & pedagogical uses of AI	AI supports creativity, requires teacher readiness
Xu and Fan (2022)	Systematic review	High school	STEM	AI types in STEM	AI tools improve learning outcomes, affective growth
Awang et al. (2025)	SLR	K-12	Math	AI for adaptive learning	Highlights tutoring, feedback, and analytics roles
Qothrunnada and Maghfiroh (2025)	SLR	School level	Math	AI chatbots	Emphasis on increased chatbot use since 2020
Chng et al. (2023)	Review	School education	STEM	Immersive Tech + AI	Supports personalization and real-time feedback
Almasri (2024)	PRISMA-SLR	K-12	Science	AI for quizzes & feedback	Enhances assessment, prediction, visualization
Yusuf (2025)	Meta-review	STEM education	STEM	AI implementation gaps	Highlights tech overuse, limited pedagogy research
Fan et al. (2023)	SLR	K-12 & higher education	STEM	AI in assessment	Academic, learning, and instructional diagnostics
Bozkurt et al. (2021)	SLR (PRISMA)	General education	STEM	EdTech + AI	AI boosts outcomes, raises ethical concerns
Saltz et al. (2019)	Theoretical	Higher education	CS	AI ethics	Introduces structured AI ethics teaching
Chen et al. (2018)	Empirical study	High school	STEM	Adaptive AI	Improved performance and reduced dropout
Schmid et al. (2021)	Meta-analysis	Secondary	Science	AI tutoring	Boosts cognitive load balance & concept mastery
Tang et al. (2020)	Case study	K-12	Science	AI-lab simulation	Enables virtual experiment modeling
Weng et al. (2021)	Empirical study	Secondary	Math	Predictive AI	Tracks performance patterns
Garcia-Sanz-Calcedo et al. (2020)	Review	Higher education	Engineering	AI tutors	Helps in autonomous learning systems
Singh et al. (2024)	Mixed-methods	Pre-service teachers	STEM	GenAI tools	Promotes critical thinking, risk of AI misuse
Long and Magerko (2020)	Design-Based	College STEM	STEM	Creative AI	Supports innovative project-based learning
Huang et al. (2021)	Meta-analysis	K-12	Math	Intelligent systems	Increases retention and engagement
Melesse and Chekol (2022)	SLR	K-12	STEM	Curriculum AI	Helps create data-driven curricula
Phan et al. (2019)	Mixed methods	Higher education	STEM	NLP tools	Supports STEM report writing
Bui and Nguyen (2023)	Experimental study	High school	STEM	Robotics + AI	Fosters hands-on STEM skills
Kim et al. (2020)	Case study	Secondary	Science	AI assistants	Supplements real instructors
Sahu and Jain (2023	Quasi-experimental	Engineering	STEM	Dropout prediction	Early warning system
Noor et al. (2022)	SLR	K-12	STEM	Fairness AI	Tackles bias in AI-based STEM tools
Ozturk and Aydin (2021)	Controlled study	Secondary	Math	AI for personalization	Enhanced math achievement
Vega et al. (2017)	Case study	University	STEM	Smart grading	Enables real-time feedback
Lim et al. (2023)	Pilot study	K-12	Math	GenAI	Improved engagement; teacher support needed
Pal and Sengupta (2022)	Survey	High school	STEM	Simulated AI labs	Enhances accessibility and safety

Table 2 shows the AI in STEM education (2014-2024).

Inter-Rater Reliability and Reviewer Validation

To enhance methodological rigor, all screening and coding procedures were conducted independently by two reviewers. Title and abstract screening, eligibility assessment, and final inclusion decisions were compared across reviewers. Inter-rater agreement was calculated using **Cohen's kappa coefficient**, yielding an agreement level of **K = 0.87**, indicating strong reliability. Any disagreements were resolved through discussion until consensus was achieved. For coding consistency, a pilot coding process was conducted using five randomly selected articles, and the coding framework was refined prior to full data extraction.

Quality Assessment of Included Studies

All included studies underwent a formal methodological quality appraisal using the Critical Appraisal Skills Program (2018) checklist for qualitative research and the Mixed Methods Appraisal Tool (2018) for quantitative and mixed-methods studies. Methodological rigor was evaluated across five criteria:

(a) clarity of research objectives,

(b) suitability of the study design,

(c) adequacy of data collection and analytical procedures,

(d) transparency and completeness of reporting, and

(e) coherence and credibility of study conclusions.

Based on Critical Appraisal Skills Program (2018) and Mixed Methods Appraisal Tool (2018) evaluation criteria, **18 studies were classified as high quality** and **12 as moderate quality; no low-quality studies were retained** in the final synthesis. No study was excluded solely on quality grounds; however, methodological strength informed the weighting of evidence during thematic synthesis, with greater interpretive emphasis given to higher-quality studies to enhance the trustworthiness of findings

RESULTS

This section presents a synthesized analysis addressing the predefined research questions, drawing upon the comprehensive data extracted from the thirty selected studies concerning the integration of AI in STEM education.

Dominant Themes and Domains Explored in the Integration of AI in STEM Education

The reviewed literature primarily explores pedagogical and technological themes within the context of AI integration. Dominant themes include the enhancement of personalized and adaptive learning (Awang et al., 2025; Chen et al., 2018; Ozturk & Aydin, 2021), the development and application of intelligent tutoring systems and problem-solving tools (Garcia-Sanz-Calcedo et al., 2020; Schmid et al., 2021; Sutomo & Turmudi, 2025), and advancements in AI-driven assessment and learning analytics (Almasri, 2024; Fan et al., 2023; Weng et al., 2021). A significant emphasis is also placed upon the utilization of simulations and virtual laboratories (Arifin et al., 2025; Pal & Sengupta, 2022; Tang et al., 2020) to foster experiential learning. Emerging themes include the role of generative AI (GenAI) and chatbots in instructional delivery (Lim et al., 2023; Qothrunnada & Maghfiroh, 2025) and the ethical considerations surrounding AI deployment (Salih et al., 2024; Saltz et al., 2019; Noor et al., 2022).

In terms of domains, the integration of AI is most extensively explored across mathematics (Awang et al., 2025; Sutomo & Turmudi, 2025; Weng et al., 2021) and science education (Almasri, 2024; Arifin et al., 2025; Schmid et al., 2021). Broader STEM contexts are frequently investigated, encompassing interdisciplinary applications (Chng et al., 2023; Singh et al., 2024; Xu & Fan, 2022; Yusuf, 2025). While less numerous, dedicated studies are also observed within engineering (Garcia-Sanz-Calcedo et al., 2020) and computer science (Saltz et al., 2019), often addressing specialized aspects such as AI ethics in machine learning curricula. Educational levels spanning K-12 and higher education receive substantial scholarly attention, indicating widespread applicability across the educational continuum.

Methodological Approaches Employed in Studies Between 2014-2024

The methodological landscape of the reviewed studies (all published or projected for publication between 2017 and 2025, thus falling within the 2014-2024 timeframe) is characterized by a significant preponderance of SLR, bibliometric reviews, and meta-analyses (Arifin et al., 2025; Awang et al., 2025; Bozkurt et al., 2021; Fan et al., 2023; Huang et al., 2021; Melesse & Chekol, 2022; Noor et al., 2022; Schmid et al., 2021; Xu & Fan, 2022; Yusuf, 2025). This emphasis on review methodologies underscores a collective effort within the academic community to synthesize burgeoning research, identify overarching patterns, and establish foundational knowledge bases.

In addition to review-based approaches, empirical investigations constitute a substantial segment of the literature. These include empirical studies (Chen et al., 2018; Weng et al., 2021), case studies (Kim et al., 2020; Tang et al., 2020; Vega et al., 2017), experimental studies (e.g., Bui & Nguyen, 2023), quasi-experimental studies (e.g., Sahu & Jain, 2023), and controlled studies (e.g., Ozturk & Aydin, 2021), which provide direct evidence of AI's impact. The application of mixed-methods research (e.g., Phan et al., 2019; Singh et al., 2024) is also observed, indicating a holistic approach to understanding complex AI-education dynamics. Furthermore, theoretical studies (e.g., Saltz et al., 2019) contribute conceptual frameworks, and design-based research (e.g., Long & Magerko, 2020) informs the iterative development of AI-enhanced educational interventions. The methodological diversity reflects the multifaceted nature of AI's integration into educational contexts, requiring varied approaches to comprehensively evaluate its effectiveness and implications.

Trends in the Evolution of AI Tools and Pedagogical Practices in STEM Contexts

Trends in AI tools reflect a shift from foundational applications towards more sophisticated and human-like interactions. Early emphasis on AI for tutoring, adaptive learning, and problem-solving remains prominent (e.g., Awang et al., 2025; Sutomo & Turmudi, 2025), but a noticeable evolution towards GenAI and AI chatbots is evident, particularly with an emphasized increase in chatbot use since 2020 (e.g., Lim et al., 2023; Qothrunnada & Maghfiroh, 2025; Singh et al., 2024). This indicates a move towards AI systems capable of content generation and more natural conversational interfaces. The integration of immersive technologies with AI (e.g., Chng et al., 2023) and robotics with AI (e.g., Bui & Nguyen, 2023) signifies a trend towards more experiential and hands-on learning facilitated by advanced technological convergence. Furthermore, AI's role in predictive analytics and sophisticated assessment tools continues to evolve, enabling more granular insights into learning patterns and academic diagnostics (e.g., Fan et al., 2023; Sahu & Jain, 2023; Weng et al., 2021).

Regarding pedagogical practices, a clear trend towards enhanced personalization and adaptive instruction is observed, aiming to optimize learning paths for individual students (e.g., Chen et al., 2018; Ozturk & Aydin, 2021). The increased use of AI for real-time feedback (e.g., Chng et al., 2023; Vega et al., 2017) and simulations in virtual laboratories (e.g., Pal & Sengupta, 2022; Tang et al., 2020) indicates a shift towards more dynamic and interactive learning environments. Pedagogical benefits derived from AI include boosts in student interaction, motivation, and engagement (e.g., Huang et al., 2021; Sutomo & Turmudi, 2025), alongside improved learning outcomes and affective growth (e.g., Xu & Fan, 2022). The findings also suggest a growing recognition of AI's capacity to support higher-order thinking skills such as creativity and critical thinking, particularly through innovative project-based learning (e.g., Long & Magerko, 2020; Singh et al., 2024).

How the Selected Studies Address the Challenges and Ethical Concerns in AI-STEM Education

The selected studies acknowledge and, in varying degrees, address critical challenges and ethical concerns associated with AI integration in STEM education. A recurring concern pertains to the necessity of teacher readiness for effective AI utilization, emphasizing the need for professional development and pedagogical adaptation (e.g., Lim et al., 2023; Salih et al., 2024). Relatedly, the literature identifies issues such as tech overuse and a perceived limited body of pedagogy-focused research on AI applications (e.g., Yusuf, 2025), indicating areas requiring further scholarly attention.

Ethical dimensions are explicitly addressed, particularly concerning the risks of AI misuse (e.g., Singh et al., 2024) and the imperative to tackle bias and ensure fairness within AI-based STEM tools (e.g., Noor et al., 2022). One study specifically introduces and advocates for the integration of structured AI ethics teaching within machine learning courses (e.g., Saltz et al., 2019), thereby promoting responsible AI development and deployment from the curriculum level. While the predominant narrative often focuses on AI's positive impact on learning outcomes, these studies collectively highlight a burgeoning awareness of the socio-ethical responsibilities inherent in the widespread adoption of AI in educational settings, urging proactive measures to mitigate potential adverse effects and ensure equitable implementation.

THEMATIC ANALYSIS

Thematic synthesis followed Braun and Clarke's (2006) six-phase framework. All studies were coded deductively and inductively. Initial codes were generated from research questions (e.g., assessment, personalization, ethics), followed by open coding to capture emergent patterns. Codes were clustered into categories, reviewed for coherence, and refined into higher-level themes. NVivo-style matrix coding techniques were applied using Excel for cross-tabulation across educational levels, AI focus, and STEM domains. Inter-coder reliability was maintained through regular calibration meetings and revision of the codebook.

AI Applications and Learning Enhancement in STEM

This cluster encompasses studies that primarily investigate the diverse applications of AI tools and their direct impact on improving learning processes and outcomes within STEM disciplines. Key findings reveal that AI significantly enhances labs, simulations, and personalized feedback (Arifin et al., 2025), thereby fostering a more interactive and adaptive learning environment. AI tools are consistently shown to improve learning outcomes and contribute to affective growth (Huang et al., 2021; Xu & Fan, 2022), increasing retention and engagement (Huang et al., 2021). Specific applications highlighted include AI for tutoring and problem-solving (Awang et al., 2025; Schmid et al., 2021; Sutomo & Turmudi, 2025), which boost interaction and motivation. Predictive AI tools are employed to track performance patterns (Weng et al., 2021) and facilitate early warning systems for student dropout (Sahu & Jain, 2023), thereby enhancing assessment and prediction capabilities (Almasri, 2024). Furthermore, AI-driven experiments and simulated labs enable virtual experiment modeling (Tang et al., 2020) and enhance accessibility and safety (Pal & Sengupta, 2022), offering practical advantages for STEM instruction.

Pedagogical Innovations and Learner Support

This cluster focuses on how AI facilitates novel pedagogical approaches and provides comprehensive support for learners across various educational levels. The primary innovation is in adaptive learning and personalization (Awang et al., 2025; Chen et al., 2018; Ozturk & Aydin, 2021), which has been demonstrated to lead to enhanced math achievement (Ozturk & Aydin, 2021) and improved performance, alongside reduced dropout rates (Chen et al., 2018). AI for tutoring, feedback, and analytics roles is consistently highlighted (Awang et al., 2025; Chng et al., 2023), with AI-based evaluation tools enabling real-time feedback (Vega et al., 2017) and supplementing real instructors (Kim et al., 2020). The role of AI in supporting creativity (Salih et al., 2024) and fostering hands-on STEM skills through applications like AI-powered robotics (Bui & Nguyen, 2023) represents a significant pedagogical shift. AI is also instrumental in supporting innovative project-based learning (Long & Magerko, 2020) and aiding in autonomous learning systems (Garcia-Sanz-Calcedo et al., 2020), indicative of a move towards more student-centric and dynamic educational paradigms.

Challenges, Ethics, and Teacher Readiness

This cluster addresses the inherent challenges, ethical considerations, and the critical need for teacher preparedness in the widespread adoption of AI in STEM education. A fundamental concern is that AI supports creativity but requires teacher readiness (Salih et al., 2024), indicating a gap in current professional development. Studies highlight AI implementation gaps and concerns regarding tech overuse and limited pedagogy research (Yusuf, 2025). The emergence of GenAI tools, while promoting critical thinking, also introduces the risk of AI misuse (Singh et al., 2024). Furthermore, a significant ethical dimension revolves around the necessity to tackle bias in AI-based STEM tools to ensure fairness (Noor et al., 2022). The importance of integrating structured AI ethics teaching is emphasized (Saltz et al., 2019), advocating for a proactive approach to responsible AI development. These challenges underscore the need for thoughtful policy, curriculum design, and educator training to fully harness AI's potential while mitigating its associated risks.

RESEARCH GAPS AND FUTURE DIRECTIONS

Despite the proliferation of research on AI in STEM education, several discernible gaps persist within the extant literature, indicating critical avenues for future inquiry. There is a paucity of longitudinal studies on AI's impact, which impedes a comprehensive understanding of its sustained effects on learning outcomes, pedagogical practices, and educational systems over extended periods. Similarly, limited real-classroom implementation research suggests a disconnect between theoretical frameworks and practical application, necessitating more empirical investigations conducted within authentic instructional environments to validate and refine AI interventions.

Furthermore, the integration of AI is underexplored in engineering as compared to mathematics and science disciplines. This disparity necessitates dedicated research to ascertain AI's specific affordances and challenges within engineering education, which often involves distinct pedagogical approaches and subject matter complexities. A pressing need also exists for the development and rigorous evaluation of AI-literate teacher training programs. The effective integration of AI into

Table 3. Matrix of research topics and study attributes, highlighting underexplored areas

Topic/study attribute	Higher education	K-12	Primary education	Teacher training	Ethics focus
Personalized learning	12	7	3	2	1
AI-driven assessment	8	4	1	1	2
Generative AI tools	9	5	1	1	1
Equity & access	4	3	1	1	2
Longitudinal impact	2	1	GAP	GAP	GAP

STEM curricula is contingent upon educators possessing the requisite knowledge, skills, and confidence to leverage AI tools responsibly and pedagogically, a domain currently lacking extensive empirical investigation. Addressing these research gaps will contribute to a more holistic and evidence-based understanding of AI's transformative potential in STEM education.

Table 3 is the matrix of research topics and study attributes, highlighting underexplored areas.

CONCLUSION

Findings were interpreted considering the quality appraisal outcomes to ensure stronger inference from higher-rated empirical and review studies. The synthesis of thirty key studies unequivocally demonstrates that AI holds strong potential to enhance STEM education across various educational levels and contexts. AI applications offer unprecedented opportunities for personalized learning, adaptive instruction, advanced assessment, and immersive experiential learning, thereby enriching the educational landscape. However, the realization of this potential is predicated upon a critical caveat: AI must be implemented with ethical, equitable, and pedagogically sound practices. The reviewed literature consistently highlights the importance of addressing concerns related to teacher readiness, potential biases within AI systems, and the responsible use of AI tools to avoid misuse. Ultimately, a balanced focus on technological innovation and educational theory is needed. Future efforts must transcend mere technological integration, emphasizing the symbiotic relationship between advanced AI capabilities and robust pedagogical frameworks. This holistic approach will ensure that AI serves as a powerful instrument for educational advancement, fostering not only enhanced academic outcomes but also equitable and ethically sound learning experiences in STEM.

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