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MAPPING THE LANDSCAPE: A COMPREHENSIVE ANALYSIS OF ARTIFICIAL INTELLIGENCE INTEGRATION IN STEM EDUCATION THROUGH MIXED-METHODS APPROACH[1]

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Abstract. This study utilizes a mixed-methods approach, combining thematic analysis and bibliometric analysis, to explore the complex landscape of artificial intelligence (AI) integration in STEM education. Through a meticulous search of the journal articles in the Web of Science and Scopus databases, utilizing keywords "STEM" and "artificial intelligence," we identified 490 publications from various research domains, including Education, Social Sciences, Philosophy, History, Psychology, Arts and Humanities, Communication, and Behavioral Sciences. After a stringent screening and the removal of duplicates, 66 articles published between January 2009 and February 2024 were extracted. Our findings indicate a notable upward trajectory in the number of publications, particularly since 2021, with 2023 emerging as the pinnacle year, housing 50% of the total publications. The thematic analysis of the articles reveals five overarching themes: 1) Integration of Modern Technology in Education; 2) AI in Educational Support Systems; 3) AI in Curriculum Development; 4) Impact of AI on Student Learning Outcomes; and 5) Inclusivity, Diversity, Equity, and Policy Considerations. Furthermore, our study illuminates emerging trends, influential works, and collaborative networks within this field, while also exploring the extent of Open Access availability, thereby fostering opportunities for knowledge dissemination and collaboration. In sum, this research enriches our comprehension of the current landscape and future trajectories of AI integration in STEM education, offering valuable insights for researchers, educators, and policymakers.

Keywords. STEM, artificial intelligence (AI), bibliometric analysis, thematic analysis

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INTRODUCTION

The integration of Artificial Intelligence (AI) in education, particularly in STEM (Science, Technology, Engineering, and Mathematics) fields, rapidly transforms how learning and teaching occur in the 21st century. As educational systems worldwide grapple with preparing students for an increasingly complex and technology-driven world, AI offers promising solutions to enhance personalized learning, improve educational outcomes, and foster inclusivity. The advent of AI technologies, such as adaptive learning systems, intelligent tutoring, and automated assessment tools, has begun to shift the educational landscape from traditional, one-size-fits-all approaches to more tailored and dynamic experiences that cater to individual student needs.

This paper aims to map the current landscape of AI integration in STEM education through a mixed-methods approach, combining thematic and bibliometric analyses. By examining the breadth and depth of research published on this topic, the study seeks to identify key themes, emerging trends, influential works, and collaborative networks within the field. This comprehensive analysis not only highlights the rapid growth of interest in AI's educational applications but also underscores the importance of addressing ethical considerations, technological challenges, and the need for professional development among educators.

Through this exploration, we aim to provide valuable insights that can guide future research, inform educational practices, and support policymakers in harnessing AI's full potential to revolutionize STEM education. The findings from this study will serve as a foundation for understanding how AI is currently shaping educational environments and what opportunities and challenges lay ahead.

What is STEM?

STEM represents a modern interdisciplinary approach to the educational process (Hoi, 2021). As Sanders (2009) highlights, the acronym STEM was coined around thirty years ago, and the term was popularized by the U.S. National Science Foundation to promote an integrated approach to scientific knowledge in the areas of Science, Technology, Engineering, and Math, which are naturally interconnected. Instead of teaching subjects separately, the STEM approach is designed to connect and integrate subject content into a unified whole. These activities are based on projects and research tasks that involve problematic issues and situations, with a special emphasis on interdisciplinary learning (Golubović-Ilić, 2023; Filipović, 2023).

This teaching model is based on research and project activities to better equip students for solving complex situations in everyday life (Sneideman, 2013; Mejias et al., 2021; Cekić-Jovanović & Gajić, 2022; Filipović, 2023; Golubović-Ilić, 2023). To clarify the advantage of an integrative approach to teaching, authors highlight examples of applying mathematical knowledge in computing and vice versa, using computers to solve various mathematical operations and problems (Marić, in: Cekić-Jovanović & Gajić, 2022). Through an integrative or holistic approach to education, we achieve the overall development of all scientific disciplines involved and contribute to their better interconnection (Milić & Mladenović, 2022).

It is crucial for children to start developing skills recognized as necessary for living in the modern world from an early age. In other words, children must learn how to adapt to changes over time in a highly efficient way. Through integrative educational models such as STEM, students are introduced to an unknown, problem-based environment where they are required to use prior knowledge and experiences to solve the current situation and problem they are facing. Within these teaching models, students develop different stages of thought processes and cognitive activities such as reflection, connection, and reasoning, among others. This approach helps students "build a foundation of knowledge they can apply in everyday life" (Golubović-Ilić, 2023:192).

As the authors point out, there are no restrictions, i.e. no lower age limit for introducing and familiarizing children with the STEAM concept of learning. Some studies indicate that early childhood experiences are significant for developing brain structures, which later influence the types and levels of future abilities in adulthood. Accordingly, McClure and colleagues emphasize how early childhood experiences with STEAM learning can contribute to overall cognitive development, and mental, motor, and emotional aspects of personality (McClure et al., 2017). Since lived experiences form the basis for cognitive development (Van Keulen, 2018), early exposure to scientific phenomena enables better and deeper exploration of scientific concepts during formal education. In other words, when children are familiar with and exposed to scientific concepts through play and apply the STEM approach to learning, at that moment, "scientific literacy begins, or the seed of science is planted" (Eshach & Fried, in: Golubović-Ilić, 2023:197). Research has shown that children can adopt scientific terms and develop an understanding of scientific facts from an early age, and for that, they need a stimulating environment that provides opportunities for exploration, an encouraging space, and adequate communication (between teacher and student), whether in a formal or informal context (McClure, 2017; Golubović-Ilić & Ćirković-Miladinović, 2020). It is precisely in such "temporal spaces" that children develop various social relationships, socialize, improve communication skills, and gain knowledge

about the world and scientific phenomena through play and exploration (Van Oers, 2013).

If we were to briefly describe the essence of the STEM concept and its derivatives (STEAM, STREAM, STEMIE), we could say that it mirrors life in a small and safe environment – it is a process of trial and error, searching for truth, testing ideas, or initial hypotheses. As De Jarnette optimistically states, for children, every mistake is an opportunity for a new beginning, as they are energetic, persistent, and full of enthusiasm like at no other stage of life (De Jarnette, 2018). Hence, they create opportunities for learning new truths about life every day.

What is AI?

Artificial Intelligence (AI) was formally introduced as a concept in 1955 during a seminal summer workshop at Dartmouth College, marking the beginning of AI research (McCarthy et al., 1955). At its essence, AI involves programming machines – be they computers, robots, or other systems – to perform tasks typically associated with human intelligence. While definitions of AI can vary, a widely accepted description by Copeland (2020) defines AI as the capability of a machine to execute tasks characteristic of intelligent beings, such as reasoning, symbolic thinking, generalization, and learning from experience. Despite extensive research, fully understanding AI remains a challenge, largely due to unresolved questions surrounding human intelligence, consciousness, and the mind.

In modern discussions, AI often evokes images of sophisticated systems that mirror human cognitive abilities – a notion that has both inspired and sparked debate. This debate, ongoing for decades (e.g., Searle, 1980), has gained renewed attention with the advent of advanced AI models like GPT-4 (https://openai.com/chatgpt/), which have expanded our understanding of AI's potential, particularly in natural language processing and problem-solving.

AI's potential in education is increasingly recognized, particularly for enhancing personalized learning and improving operational efficiency. However, this potential is coupled with significant concerns, including ethical dilemmas, technological challenges, and the need for substantial professional development to effectively implement AI in educational contexts (e.g. Aghaziarati, Nejatifar & Abedi, 2023; Tondeur et al., 2019).

For example, one significant application of AI in education is adaptive learning, where technologies are employed to tailor educational content to individual learners' abilities and progress (Capuano & Caballé, 2020). These systems aim to optimize learning efficiency by dynamically adjusting course materials to fit each learner's needs, using both automated systems and instructor interventions.

The concept of adaptive learning emerged in the 1970s, building on the initial AI applications in education that sought to emulate human teaching. However, the modern incarnation of adaptive learning, characterized by technologies like knowledge representation, user modeling, curriculum sequencing, and machine learning, took shape in the early 2000s with the rise of online education and a focus on personalized learning.

Recent advancements in AI-driven adaptive learning include:

(1) Conversational Agents: AI systems that engage with students in discussions, providing personalized guidance and motivation.

(2) Sentiment Analysis: Techniques that assess students' emotions in real time, enabling the delivery of targeted feedback.

(3) Recommender Systems: Systems that suggest additional learning materials based on a student's prior knowledge or observed learning patterns.

Despite the potential of adaptive learning technologies, their widespread adoption is limited by challenges such as the high costs of implementation and the complexities of integrating these technologies into existing educational frameworks. However, initiatives like the European colMOOC Project and the Precision Education Initiative (Hart, 2016) at National University (California, USA), among others, reflect the growing investment and interest in these technologies.

For example, a systematic literature review from 2023 (Heeg & Avraamidou, 2023) identified nine key AI applications in education, including automated assessment and intelligent tutoring systems, particularly within STEM fields like geoscience and physics. These applications have been shown to significantly impact educational outcomes, such as learning achievement and argumentation skills.

Similarly, a 2023 review by Gligorea et al. explored AI and machine learning in e-learning, emphasizing their role in personalizing learning experiences, optimizing learning paths, and enhancing student engagement. Despite challenges related to data privacy and system complexity, the potential of AI to revolutionize education remains significant.

Another prominent application of AI in education is intelligent tutoring systems, which have been extensively studied (Lin, Huang & Lu, 2023; Mousavinasab et al., 2021). These systems offer personalized instruction and feedback, further demonstrating AI's transformative potential in shaping the future of education.

METHOD

This study employs a mixed-methods approach, integrating thematic and bibliometric analyses, to investigate the integration of artificial intelligence (AI) in STEM education. The thematic analysis focused on identifying specific "facets" of this integration, including applications, challenges, and trends, which are detailed in a dedicated section of this paper. A comprehensive search was conducted in the Web of Science (WoS) and Scopus databases using the keywords "STEM" and "artificial intelligence." To reduce irrelevant results stemming from the frequent use of "stem" in biology, life sciences, and related disciplines, the search was restricted to fields such as Education, Social Sciences, Philosophy, History, Psychology, Arts and Humanities, Communication, and Behavioral Sciences. While the phrasing of these fields differed slightly between WoS and Scopus, the scope remained consistent. This search yielded an initial pool of 490 publications: 143 (29.18%) from WoS and 347 (70.82%) from Scopus.

The dataset was refined by filtering for journal articles, excluding conference proceedings, editorials, letters, short surveys, books, and book chapters. Duplicate entries (68 in total) were identified and removed using DOIs or, where unavailable, paper titles. Both authors independently assessed the remaining articles using predefined relevance criteria. The srticles were included if they explicitly addressed both STEM education and AI in a meaningful and interconnected manner.

A paper was considered "meaningful" if it provided substantive discussion or analysis of AI's role within STEM education, such as its influence on curriculum development, pedagogical strategies, or student outcomes. "Interconnected" was defined as demonstrating a clear linkage between STEM education and AI, including practical applications, theoretical frameworks, or empirical findings. For instance, studies discussing the use of AI-based tools to enhance STEM teaching and learning were included, while papers mentioning "stem" (lowercase) and AI in unrelated contexts, such as life sciences or robotics research, were excluded.

After applying these criteria, 66 unique journal articles remained: 38 (57.58%) from WoS and 28 (42.42%) from Scopus, published between January 2009 and February 2024.

To resolve discrepancies in eligibility assessments, a collaborative "matching phase" was conducted, during which papers with differing inclusion/exclusion decisions were reviewed and discussed until consensus was reached. This rigorous filtering and consensus-building process ensures that the final dataset comprises high-quality, relevant, and focused articles aligned with the study's objectives.

The final dataset's distribution by year of publication (WoS + Scopus) is as follows: 2024 – 5; 2023 – 33; 2022 – 12; 2021 – 9; 2020 – 2; 2019 – 1; 2017 – 1; 2016 – 1; 2011 – 1; 2009 – 1.

Thematic Analysis

Thematic analysis is defined as a scientific method used to identify, analyze, interpret, and report on recognized themes within the data being researched (Braun & Clarke, 2006). Thematic analysis is also described as "a systematic examination of qualitative material to identify broader patterns of meaning for grouping into higher-order categories/themes" (Ševkušić, 2019: 290). Due to its inherent flexibility, thematic analysis provides researchers with a wide range of possibilities for using it for various research purposes. However, it can also create difficulties if the chosen approaches are not clearly defined, explained, and specified (Vesić, Vujačić i Joksimović, 2018). The implementation of thematic analysis involves the researcher determining the criteria for the content that can be coded within a theme, as well as which and how many levels of meaning will be subject to interpretation (Ševkušić, 2019). Coding represents the fundamental process of developing themes by identifying specific items and labeling them with a predetermined symbol for coding. Since coding is a subjective act in the analysis, it is natural for it to be subject to categorical changes during the coding process itself. Considering that Thematic analysis is one of the most common forms of analysis within qualitative research, that emphasizes identifying, analyzing, and interpreting patterns of meaning (or "themes") within qualitative data, this approach is best thought of as an umbrella term for a variety of different approaches, rather than a singular method (Maguire & Delahunt, 2017).

When it comes to our research, through a meticulous search of journal articles in the Web of Science and Scopus databases, utilizing keywords "STEM" and "artificial intelligence," we identified 490 publications spanning various research domains including the following scientific fields: Education, Social Sciences, Philosophy, History, Psychology, Arts and Humanities, Communication, and Behavioural Sciences. After a stringent screening and the removal of duplicates, our analysis focused on 66 articles published between January 2009 and February 2024.

The thematic analysis was conducted based on a detailed search of two representative scientific databases. Five overarching themes include:

1. Integration of Modern Technology in Education;
2. AI in Educational Support Systems;
3. AI in Curriculum Development;

4. Impact of AI on Student Learning Outcomes; and
5. Inclusivity, Diversity, Equity, and Policy Considerations.

When discussing the first theme, *Integration of Modern Technology in Education*, it is important to highlight the leading sub-themes identified in the reviewed papers. The *Utilization of AI-supported game-based learning and project-based learning* demonstrates how artificial intelligence can enhance student engagement, creativity, and outcomes by making learning more interactive and personalized. There is also a growing emphasis on *ChatGPT and generative AI in STEM education*, where these tools are being used to support complex problem-solving and knowledge acquisition. A notable example is the exploration of students' perceptions of using ChatGPT as a virtual tutor in physics classes, where AI plays an active role in facilitating understanding and guiding learning. The conversation extends beyond the classroom, delving into the ethical implications of *ChatGPT for STEM research and higher education*, with media discourse highlighting concerns about AI's impact on academic integrity, research practices, and authorship. This is further expanded by discussions on ChatGPT's implications for industry and higher education, specifically the need for a transdisciplinary approach that bridges digital humanities and STEM. Lastly, research comparing the pairing of student teachers with in-service teachers versus ChatGPT shows intriguing results about its impact on critical thinking, learning performance, and cognitive load in integrated STEM courses, raising essential questions about the future balance between human and machine-led instruction.

The second topic, *AI in Educational Support Systems*, was developed based on three key sub-themes. The first sub-theme, *Application of AI for Didactical Approaches*, emphasizes how AI is transforming traditional teaching methods by providing personalized learning experiences, adapting content to individual student needs, and optimizing instructional strategies. The second sub-theme, *AI as a Learning-Supporting and Tutoring Tool*, highlights the role of AI as a virtual tutor, offering real-time assistance, guiding students through complex topics, and enabling more flexible, self-paced learning. The third sub-theme, *Focus on Educational Analytics, Assessment, and Evaluation for Precision Education*, explores the use of AI-driven analytics to gather and analyze big data in real time, allowing for precise assessments of student performance and personalized interventions, which help enhance learning outcomes. This approach supports the movement toward data-informed decisions in education, aiming for tailored learning experiences that meet the diverse needs of students.

The third topic, *AI in Curriculum Development*, is based on three subtopics. The first, the *Role of AI in Curriculum Design*, focuses on how AI can aid in the

development of curricula by analyzing educational needs, predicting trends, and customizing content to fit diverse learning environments. The second subtopic, *Implementation of AI in Educational Programs*, discusses the practical integration of AI tools into educational settings, enabling educators to enhance their teaching methods and create more dynamic, interactive learning experiences. The third subtopic, *The Crisis of Artificial Intelligence: A New Digital Humanities Curriculum for Human-Centered AI*, addresses the ethical and philosophical challenges posed by AI in education. It calls for a shift towards a curriculum that prioritizes human-centered AI, combining technological advancement with the principles of digital humanities to ensure that AI development aligns with human values and societal needs.

The fourth topic, the *Impact of AI on Student Learning Outcomes*, encompasses several crucial aspects. The first sub-theme, *Effects of AI on Knowledge, Skills, and Attitudes*, examines how AI-enhanced learning environments influence students' cognitive development, skill acquisition, and shifts in their attitudes toward learning. It explores the extent to which AI tools help students better understand complex concepts, improve problem-solving skills, and foster more positive engagement with their studies. The second sub-theme, *Examination of Psychological Traits in the Context of AI Integration*, delves into how the incorporation of AI in education affects students' psychological traits such as motivation, self-efficacy, and emotional resilience. This sub-theme focuses on the need to understand how AI impacts students' mental and emotional responses to learning, including stress levels, adaptability, and overall well-being.

The fifth and last topic listed in this thematic analysis, *Inclusivity*, *Diversity*, *Equity*, *and Policy Considerations*, addresses the importance of ensuring fairness and accessibility in the integration of AI in education. The first sub-theme, *Exploration of Inclusion and Diversity in AI Integration*, highlights the need to design AI systems that are inclusive and account for the diverse backgrounds, abilities, and learning needs of all students. It emphasizes how AI can either bridge or widen gaps in educational access, depending on how it is implemented. The second sub-theme, *Policy Research and Implications for Educational AI* focuses on the policies needed to regulate and guide the use of AI in education. It addresses the ethical and legal frameworks that should be established to ensure AI tools are used responsibly, equitably, and in ways that promote diversity and inclusivity. This sub-theme calls for ongoing research into the policy implications of AI, ensuring that it serves all students fairly while supporting educational equity.

Based on everything written above about the presented thematic analysis, the exploration of AI in education reveals its profound impact on modern teaching methodologies and learning experiences. AI-supported game-based

and project-based learning have been reshaping educational approaches, enhancing engagement and practical application. ChatGPT and generative AI's role in STEM education, including its use as a virtual tutor and the associated ethical implications, underscore the need for a balanced integration of technology that supports both pedagogical innovation and responsible usage. Addressing the effectiveness of AI versus human expertise in teaching, alongside discussions on transdisciplinarity and the broader implications for industry and higher education, highlights the ongoing necessity for thoughtful implementation and policy development to maximize AI's benefits while addressing potential challenges.

Bibliometric Analysis

Bibliometric analysis is a quantitative method used to analyze large volumes of scientific data, helping researchers understand the development, trends, and intellectual structure of a particular field (Donthu et al., 2021). It is particularly effective in handling extensive datasets from sources like Scopus or Web of Science and has gained popularity due to advancements in bibliometric software, such as BibExcel, which was used to conduct the present analysis.

This section addresses two key research questions: (1) Which journals are the key in the field of AI integration in STEM education? and (2) Which authors have published the most on the topic?

Key Journals. Table 1 lists the journals that have published the most research on AI integration in STEM education. Notably, *Education and Information Technologies* and *Frontiers in Education* lead the field with four publications each, followed by *Educational Technology & Society*, *International Journal of Educational Technology in Higher Education*, and *International Journal of STEM Education* with three publications each. This distribution indicates that AI integration in STEM education is a multi-disciplinary topic that spans educational technology, general education, and STEM-specific journals, reflecting its broad relevance and interdisciplinary appeal.

Table 1. Scientific journals where research on AI integration in STEM education has been published

Journals	No. of papers published
EDUCATION AND INFORMATION TECHNOLOGIES	5
EDUCATIONAL TECHNOLOGY & SOCIETY	4
INTERNATIONAL JOURNAL OF EDUCATIONAL TECHNOLOGY IN HIGHER EDUCATION	4
FRONTIERS IN EDUCATION	4
SUSTAINABILITY	3
EDUCATIONAL TECHNOLOGY & SOCIETY	4
INTERNATIONAL JOURNAL OF STEM EDUCATION	3
EDUCATION SCIENCES	2
IEEE TRANSACTIONS ON LEARNING TECHNOLOGIES	2
ACM TRANSACTIONS ON COMPUTING EDUCATION	1
ASIA PACIFIC JOURNAL OF EDUCATION	1
BORDÓN-REVISTA DE PEDAGOGIA	1
CONTEMPORARY EDUCATIONAL TECHNOLOGY	1
EDUCATIONAL STUDIES	1
FRONTIERS IN PSYCHOLOGY	1
INDUSTRY AND HIGHER EDUCATION	1
INTERNATIONAL JOURNAL OF HUMANITIES AND ARTS COMPUTING-A JOURNAL OF DIGITAL HUMANITIES	1
INTERNATIONAL JOURNAL OF SCIENCE EDUCATION	1
JOURNAL OF EDUCATION FOR BUSINESS	1
JOURNAL OF MEDICAL EDUCATION AND CURRICULAR DEVELOPMENT	1
JOURNAL OF NEW APPROACHES IN EDUCATIONAL RESEARCH	1
RESEARCH IN SCIENCE EDUCATION	1
REVISTA IBEROAMERICANA DE EDUCACIÓN	1
REVISTA PUBLICACIONES	1
SOUTH AFRICAN JOURNAL OF CHILDHOOD EDUCATION	1
THINKING SKILLS AND CREATIVITY	1
TOPICS IN COGNITIVE SCIENCE	1

Key Authors. Our analysis identified several key authors in the field, including Huang Yueh-Min (National Cheng Kung University, Tainan, Taiwan), Lee Hsin-Yu (National Cheng Kung University, Tainan, Taiwan), Lin Chia-Ju (National Cheng Kung University, Tainan, Taiwan), Wang Wei-Sheng (National Cheng Kung University, Tainan, Taiwan), and Wu Ting-Ting (National Yunlin University of Science and Technology, Yunlin, Taiwan), each of whom has published two papers. These authors are notably contributing to the evolving discourse on AI's role in enhancing STEM education through adaptive learning technologies. Their articles, such as "Leveraging computer vision for adaptive learning in STEM education: Effect of engagement and self-efficacy" and "Recognitions of image and speech to improve learning diagnosis on STEM collaborative activity for precision education", highlight emerging research focused on AI-driven tools to improve student engagement and personalized learning.

Current Trends. First, what can be noticed is that our findings indicate a notable upward trajectory in the numbers of publications, particularly since 2021, with 2023 emerging as the pinnacle year, housing 50% of the total publications. This period coincides with the popularization and significantly increased investment in research and applications of artificial intelligence in recent years, especially since the emergence of generative AI models like ChatGPT and similar technologies. It can be assumed that one of the reasons for this expansion is that this technology emerged during the COVID-19 pandemic (when people simply had the time to explore and experiment with it).

Second, it was noted that all levels of education are almost equally present (Preschool, Elementary, Secondary, and Higher Education). This finding is encouraging, as it suggests that, at all levels, so to speak, the possibilities of implementing new technological advancements in the education system are being equally researched and explored. The bibliometric analysis reveals several emerging trends in the field:

1. Increased Focus on Adaptive Learning: Many of the most cited works emphasize adaptive learning systems, which are AI technologies designed to tailor educational content to individual learner needs. This aligns with broader trends in personalized education and suggests a growing recognition of AI's potential to address diverse learning preferences and improve educational outcomes.

2. Collaborative Research Networks: The field is characterized by strong collaborative networks, with authors frequently co-authoring papers across institutions and countries. This suggests a high level of international interest and collaboration, which could accelerate the development of innovative AI applications in STEM education.

3. Diverse Applications of AI: AI applications discussed in the literature range from automated assessment and feedback systems to intelligent tutoring

and real-time learning analytics. These diverse applications underscore AI's versatility and potential to transform multiple facets of STEM education, from classroom management to content delivery and student support.

Limitations and Future Directions. Despite the progress, the field faces several challenges. First, there is a limited number of publications specifically focusing on ethical considerations, such as data privacy and algorithmic bias, which are crucial as AI technologies become more embedded in educational settings. Future research should address these gaps to ensure responsible and equitable use of AI in education.

Moreover, while the current literature covers a broad range of AI applications, there is a notable gap in longitudinal studies that evaluate the long-term impact of AI on learning outcomes in STEM fields. Addressing this gap could provide valuable insights into how AI tools can be sustainably integrated into educational practices.

Conclusion. In summary, the bibliometric analysis highlights the growing body of research on AI integration in STEM education, with key contributions from leading journals and authors in the field. The identified trends and gaps offer a roadmap for future research, emphasizing the need for continued exploration of AI's potential to enhance personalized learning and its long-term impact on STEM education.

CONCLUSION

This study provides a comprehensive analysis of the integration of Artificial Intelligence (AI) in STEM education, utilizing a mixed-methods approach that combines thematic and bibliometric analyses. The findings reveal a notable increase in publications on AI in STEM education since 2021, reflecting the growing interest and investment in this field. Key themes identified include the integration of modern technology in education, the role of AI in educational support systems and curriculum development, the impact on student learning outcomes, and considerations of inclusivity, diversity, and policy.

Our analysis highlights several emerging trends, such as the focus on adaptive learning systems and the importance of collaborative research networks, which demonstrate the potential of AI to personalize learning experiences and improve educational outcomes across all levels of education. However, the study also identifies significant challenges, including ethical concerns related to data privacy and algorithmic bias, as well as the need for further research into the long-term impacts of AI on learning outcomes.

As AI continues to evolve and permeate educational contexts, it is crucial that researchers, educators, and policymakers work together to address these challenges and harness AI's potential responsibly. Future research should focus on bridging existing gaps, such as exploring ethical implications more deeply and conducting longitudinal studies to assess the sustainability of AI tools in educational settings. By doing so, we can ensure that AI integration in STEM education not only enhances learning but also contributes to a more equitable and inclusive educational landscape.

In sum, this study maps the current state of AI integration in STEM education, offering a roadmap for future research and providing insights that can help shape the future of education in an increasingly AI-driven world.

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Appendix: *The list of the 66 articles that were analyzed in the paper*

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