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Review Article

Pedagogical incorporation of artificial intelligence in K-12 science education: A decadal bibliometric mapping and systematic literature review (2013-2023)

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Artificial intelligence (AI) technologies continue to revolutionize various sectors, including their incorporation into education, particularly in K-12 science education, which has become evidently significant. This paper presents a bibliometric analysis and systematic review that examines the incorporation of AI technologies in K-12 science education. A total of 20 studies, comprising journal articles and conference proceedings published between 2013 and 2023 and sourced from the Scopus database, were analyzed to identify leading journals, influential papers, and authors, and county-wise contributions. The study reveals that AI technologies, including robotics, chatbots, machine learning, automated scoring - feedback, and neural networks, have demonstrably enhanced learning outcomes, increased student engagement, and facilitated personalized education in science classrooms. Further, the review identifies diverse methodological approaches and pedagogical strategies, including hands-on learning, blended learning models, inquiry-based methods, and feedback-based learning, as practical means of incorporating AI within science classrooms. Moreover, the key findings emphasized the importance of professional development, infrastructure investment, and ethical guidelines to support equitable implementation of AI in science education. This study also advocates future research investigating long-term impacts, ethical considerations, and qualitative insights to fully understand AI's potential in enhancing K-12 science education.

Keywords: Artificial intelligence; K-12 science education; Systematic review; Bibliometric mapping; Pedagogical strategies

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1. Introduction

Artificial intelligence [AI] stands at the forefront of innovation in the present technologically driven world, profoundly impacting various sectors, including education (Habbal et al., 2024; Owoc et al., 2021). AI technologies, including machine learning [ML], robotics, predictive analytics, natural language processing [NLP], and expert systems, are drastically transforming how we live, work, and learn (Gruetzemacher & Whittlestone, 2022; Khurana et al., 2023; Liu et al., 2018; Sarker, 2021). Moreover, AI is gaining prominence in the educational sphere for its potential to revolutionize traditional teaching methods (Gill et al., 2024; Kabudi, 2022), optimize educational

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outcomes, and foster a more engaging and efficient learning environment by offering personalized learning experiences, providing adaptive feedback, and delivering data-driven insights (Huang et al., 2023; Srinivasa et al., 2022). Its educational applications range from intelligent tutoring systems [ITS] that tailor instruction to individual student needs to AI-driven analytics that help educators understand and address learning gaps by analyzing data from various sources, including assessments and interaction logs in identifying knowledge deficiencies, skill limitations, performance differences, and engagement issues, ultimately enabling more targeted and effective interventions (Ali et al., 2024; Humble & Mozelius, 2022; Lin et al., 2023).

As a product of scientific advancement, the disruptive role of AI in science education [AISE] is particularly noteworthy (Heeg & Avraamidou, 2023), given its ability to address complex pedagogical challenges and enhance student engagement (Cooper, 2023). AI-powered tools and applications are uniquely positioned to facilitate inquiry-based learning (Herdliska & Zhai, 2023), allowing students to explore scientific concepts through interactive simulations and virtual laboratories (Chng et al., 2023). For instance, AI-driven platforms can create dynamic, real-time models of chemical reactions or physical processes, enabling students to visualize and experiment with challenging or impractical scenarios to replicate in a conventional classroom environment. Furthermore, AI can significantly improve science classrooms' assessment and feedback processes (Minn, 2022). Intelligent tutoring systems [ITS] can provide immediate, personalized feedback to students, enhancing their learning outcomes while maintaining student motivation and interest in the subject (Alam, 2023). AI also plays a key role in supporting differentiated instruction in science classrooms. Additionally, by analyzing vast amounts of student data, AI systems can identify individual learning patterns and needs, enabling educators to tailor their instructional strategies accordingly (Alfredo et al., 2024). This ensures that each student receives the appropriate level of challenge and support, fostering a more inclusive and effective learning environment (Chen et al., 2023).

As AI technologies continue to advance, their incorporation into K-12 science education promises to transform how science is taught while cultivating interest and proficiency in STEM fields among learners from a young age (Clark, 2023; Erduran, 2023). However, despite the increasing research on AI applications in education, there is still a noticeable gap in the literature regarding its pedagogical incorporation, specifically within K-12 science classrooms. Previous reviews have often provided valuable insights into AI applications in education but have focused on broader contexts (Bond et al., 2024; Crompton et al., 2024) or specific AI trends (Gao et al., 2024; Wu & Yu, 2024), neglecting to analyze the pedagogical implications in science education systematically. While a few review studies have touched on the topic of AI in K-12 science education, many have not covered the timeframe up to 2023 or focused solely on specific research trends of AI applications in science education (Jia et al., 2024; Xu & Ouyang, 2022; Zhai et al., 2020). These reviews, while informative, fall short of providing a detailed examination of how AI has been incorporated into K-12 science classrooms from a pedagogical standpoint. Therefore, this bibliometric mapping and systematic review aims to fill this gap by examining literature from 2013 to 2023, specifically focusing on AI's trends and pedagogical applications in K-12 science classrooms.

To guide this review, the following research questions are posed:

RQ 1) Which journals are the leading research publishers on pedagogical incorporation of AI in K-12 science education, what are the most influential papers and authors driving the discourse in this field, and how do these contributions vary by country?

RQ 2) What AI technologies have commonly been utilized in K-12 science education?

RQ 3) How does the incorporation of AI in K-12 science education vary across grade levels, and what methodological approaches are commonly used to study this?

RQ 4) What are the key pedagogical approaches for incorporating AI in K-12 science classrooms?

RQ 5) How does the incorporation of AI impact learning in K-12 science classrooms?

By systematically examining the pedagogical incorporation of AI in K-12 science classrooms from 2013 to 2023, this study aims to thoroughly grasp current trends and opportunities in this swiftly evolving field. The relevance of this study extends to its capacity to inform educational practice, policy-making, and future research endeavors aimed at optimizing AI applications in K-12 science education. Moreover, the findings of this study will enrich the theoretical understanding of AI in education while also guiding aspiring educators in utilizing AI technologies for optimizing scientific classroom instruction.

2. Literature Review

As a crucial component of information and communication technology [ICT], AI has become increasingly significant in shaping the modern world (Dave et al., 2022). AI-driven innovations such as virtual assistants, chatbots, predictive analytics, and smart and automated systems enhance efficiency and decision-making processes across industries (Mukhopadhyay et al., 2021; Rawassizadeh et al., 2019). Moreover, as AI continues to evolve, its incorporation into various facets of daily professional and personal life underscores its pivotal role in driving technological progress and enhancing human capabilities (Howard, 2019). This evolution has naturally extended into the educational sector, where AI is poised to revolutionize how we teach and learn (Brusilovsky, 2024).

2.1. Artificial Intelligence

AI refers to the simulation of human intelligence in machines designed to compute cognitive tasks, and its origins can be traced back to the early days of computer science and cybernetics in the 1940s (Haenlein & Kaplan, 2019). A pivotal moment came in 1950 when Alan Turing posed the question, "Can a machine think?" which laid the groundwork for AI (Turing, 1950, p. 433). Building on these early ideas, a significant milestone was reached in the mid-1950s during the Dartmouth Conference organized by key figures like John McCarthy and Marvin Minsky, Nathaniel Rochester, and Claude Shannon, where the term "Artificial Intelligence" was officially coined (Solomonoff, 2023). This conference is often regarded as the formal birth of AI as a distinct discipline, marking the beginning of systematic research and development in the field.

Early AI research focused on problem-solving and symbolic methods, and over the decades, advancements in computing power, data availability, and algorithms have significantly evolved AI technologies (Schmidhuber, 2007). Modern AI encompasses machine learning, robotics, deep learning, neural networks, and natural language processing, enabling machines to perform complex tasks such as image speech and emotion recognition, predictive analytics, and autonomous decision-making (Soori et al., 2023). These developments have transformed industries like healthcare, finance, and transportation and laid the foundation for AI's transformative impact on education (De Silva et al., 2020; Jan et al., 2023).

2.2. Historical Background, Theoretical Foundations, and Evolution of AI in Education (AIEd)

The journey of AI in education [AIEd] began with computer-assisted instruction in the 1960s and 1970s, laying the groundwork for more advanced AI applications (Guan et al., 2020). This evolution can be understood through the lens of constructivist learning theory (Piaget, 1973), which suggests that learners build their knowledge through active engagement with content, peers, and technology (Hof, 2021). Between 1964 and 1966, Joseph Weizenbaum at MIT developed Eliza, an early natural language processing program that acted as an interface between humans and machines (Weizenbaum, 1983). Subsequently, Jaime Carbonell created SCHOLAR, a student-oriented instructional program designed to ask and answer questions about South American geography, providing immediate feedback on learners' responses (Carbonell, 1970). Recognized as the first Intelligent Tutoring System, SCHOLAR marked a significant milestone in the application of AI to education (Doroudi, 2023). These early innovations, rooted in constructivist theory and providing immediate, personalized feedback to support learners' active construction of knowledge, have paved the way for developing more sophisticated AI technologies in education

(Lam et al., 2021). Further, by the 2000s, advancements in machine learning and natural language processing had significantly expanded AI's capabilities in educational contexts (Zhang & Aslan, 2021). This progress paved the way for recent developments such as AI-driven analytics, chatbots, automated feedback and scoring systems, and adaptive learning platforms (Ait Baha et al., 2023; Essa et al., 2023; Koltovskaia, 2020; Mizumoto & Eguchi, 2023; Ouyang, Wu, et al., 2023). These technologies offer more dynamic and interactive learning experiences, revolutionizing the educational landscape and enabling more effective and personalized learning paths (Kavitha & Joshith, 2024; Slimi, 2021). Moreover, these technologies embody the principles of social constructivism (Bruner, 2009; Vygotsky, 2012), where AI serves as a mediator in the learning process, enabling collaborative learning and the co-construction of knowledge in educational settings (Ouyang & Jiao, 2021).

2.3. Limitations of Available Systematic Reviews on AI in Science Education [AISE]

Despite the increasing interest in AI's role in education (Bahroun et al., 2023; Hopcan et al., 2023; Liang et al., 2023; Nigam et al., 2021), existing systematic reviews on AI in science education often exhibit significant limitations. Many reviews, such as those by Chng et al. (2023) and Xu and Ouyang (2022), primarily focus on broader STEM educational contexts, lacking a specific emphasis on K-12 science classrooms. Additionally, many reviews have concentrated on specific contexts without providing a comprehensive overview of pedagogical incorporation in science education. For instance, Ouyang et al. (2023) focus on AI-driven assessments in STEM, while Feng et al. (2021) examine the impact of ITSs in STEM education but fail to provide a comprehensive overview of AI's pedagogical incorporation in science education. Moreover, while reviews by Zhang and Tur (2024), Hwang and Chang (2023), and Magalhães et al. (2023) explored the use of chatbots in K-12 education, they often do not extensively address their application in science classrooms. Though these reviews often provide valuable insights into specific applications of AI, they fall short of offering a holistic view of how AI can be incorporated into K-12 science education, highlighting the need for more targeted reviews in this area. The systematic literature review by Heeg and Avraamidou (2023) highlighted various AI applications in school science, such as automated assessment, feedback, learning analytics, adaptive learning systems, and ITS. However, this review is limited to studies published up to 2021, missing more recent advancements. Furthermore, Jia et al. (2024) conducted a meticulous bibliometric and content analysis from 2013 to 2023, contributing significantly to the current review landscape of AI in the early stages of science education. While offering valuable insights, their study's focus on trends and research foci underscores the need for a more comprehensive review that explicitly addresses the pedagogical incorporation of AI within K-12 science classrooms.

In conclusion, existing systematic reviews on AISE often overlook recent advancements and have narrow scopes, while some lack a comprehensive analysis of AI's pedagogical implications in K-12 science education. Addressing these gaps is essential for thoroughly understanding AI's role in science education, thereby building on the findings from this review; a conceptual framework (Figure 1) was developed, guided by the research questions outlined in this study, to systematically address the identified gaps and provide a foundation for further investigation. This framework is informed by constructivist and social constructivist theories, focusing on six key dimensions: *Leading Journals, Influential Papers, Authors, and Country contributions,* which offer insight into the principal sources and contributors in the field; *AI Technologies*, which examines the specific AI technologies utilized in K-12 science classrooms; *Educational Grade Levels*, which explores the variation in AI integration across different educational stages; *Research Methodologies*, which reviews the approaches used to study AI's impact; *Pedagogical Approaches*, which considers various strategies for integrating AI with classroom teaching practices; and *Impact on Learning Outcomes*, which evaluates the effects of AI on student performance and engagement. By synthesizing these dimensions, the framework facilitates a thorough understanding of AI's role in science education, highlights areas needing further research, and guides the study's exploration of

AI's integration and pedagogical implications. Subsequently, a bibliometric mapping and a systematic literature review [SLR] of empirical studies on AI's integration in K-12 science education from 2013 to 2023 were conducted using the PRISMA framework, further refining the scope and focus of the research.

Figure 1
Conceptual Framework for the Study

3. Methodology

This study utilizes a systematic literature review combined with bibliometric mapping (Pulsiri & Vatananan-Thesenvitz, 2018) to comprehensively analyze the incorporation of AI in K-12 science education from 2013 to 2023. The dataset was meticulously collected from the Scopus database following the PRISMA guidelines and predefined inclusion and exclusion criteria. The SLR ensures an unbiased synthesis of existing research in a systematic manner, while bibliometric mapping visually elucidates research trends and patterns (Nightingale, 2009; van Leeuwen, 2006). By employing this dual approach, the study endeavors to deliver a thorough and up-to-date comprehension of the pedagogical incorporation of AI in K-12 science education.

3.1. Data Source and Search Strategy

The primary database used for this systematic review was Scopus, which was selected for its extensive coverage of peer-reviewed literature across various disciplines (Zhu & Liu, 2020), including education. With the insight of available bibliometric studies and SLRs on AI applications in education (Chiu et al., 2023a; Hwang & Tu, 2021; Kavitha et al., 2024; Zawacki-Richter et al., 2019), a systematic search strategy was developed to identify relevant studies. The final search string in Table 1 included keywords and phrases related to AI applications, science teaching and learning, and K-12 education. These terms were connected by the logical operators OR and AND to ensure comprehensive literature retrieval. The search terms were applied to titles, abstracts, and keywords to capture a broad range of relevant literature. This approach ensured an inclusive collection of relevant studies for the review.

3.2. Inclusion and Exclusion Criteria

Specific inclusion and exclusion criteria (Table 2) were applied to ensure the relevance and quality of the studies in the full text included in the review (Sanfilippo et al., 2020).

Table 1
Search String used in Scopus database for selecting relevant studies

Topic	*Search String*
AI Applications	"artificial intelligence" OR "machine learning" OR "deep learning" OR "fuzzy logic" OR "neural network" OR "intelligent tutor*" OR "intelligent tutoring system" OR "smart tutor*" OR "adaptive learning" OR "natural language processing" OR "prediction system" OR "computer vision" OR "learning analytics" OR "expert system" OR "robot" OR "data mining" OR "automated feedback" OR "automated grading" OR "automated assessment*" OR "automated scoring"
AND Science Teaching and Learning	"science teaching" OR "stem" OR "science learning" OR "science education" OR "science curriculum" OR "scientific argumentation" OR "chemistry" OR "physics" OR "biology" OR "environmental science" OR "aise"
AND K -12 Education	"primary education" OR "elementary education" OR "k-12 education" OR "secondary education" OR "high school" OR "junior high school" OR "primary school" OR "secondary school" OR "middle school"

Table 2
Inclusion and exclusion criteria

	Inclusion Criteria	*Exclusion Criteria*
Publication Year	Studies published from January 2013 to December 2023	Studies published before 2013 and after 2023
Document Type	Articles and Conference paper	Reviews, book Chapters, editorials, etc.
Source Type	Journal and Conference Proceedings	Books, book series, trade journals, and undefined
Language	English	Other languages (Italian, Spanish, etc.)
Focus and Context	Studies focused on using AI and AI applications in K-12 science subjects teaching and learning.	Studies not related to the use of AI and AI applications in K-12 science subjects teaching and learning.

3.3. Data Screening and Selection

The Scopus database was searched on May 25, 2024, using the developed comprehensive search string applied to all publications' titles, abstracts, and keywords, resulting in an initial yield of 1,008 studies. These records included publications from various educational journals focused on technology, such as "Education and Information Technologies," "IEEE Transactions on Learning Technologies," "Computers and Education," "Journal of Research on Technology in Education," and "International Journal of Artificial Intelligence in Education." Despite this, there were very few representations from science education journals. In response, to ensure the inclusion of relevant studies on AI incorporation within school-level science education from science education journals, we conducted targeted searches for 'Artificial Intelligence' on the websites of five reputable educational journals in the science discipline of Q1 status (Table 3), uncovering an additional 355 studies.

Table 3
Journal Search Summary

Journal Name	*ISSN*	*Number of Studies*
International Journal of Science Education	0950-0693	82
Journal of Research in Science Teaching	0022-4308	36
Journal of Science Education and Technology	1059-0145	100
Research in Science and Technology Education	0263-5143	17
Research in Science Education	0157-244x	120

Subsequently, the study followed the PRISMA guidelines to ensure a rigorous and transparent selection of studies, enhancing the credibility and replicability of the review (Page et al., 2021). After removing duplicates following the initial screening, the titles and abstracts of each study were reviewed using well-established inclusion and exclusion criteria, resulting in an initial selection of 34 studies. Following a thorough full-text review, 14 studies were removed for failing to meet the inclusion criteria, leaving a final total of 20 studies included in this review. The PRISMA flow diagram (Figure 2) visually represents the data screening and selection process, showing the number of studies identified, screened, assessed for eligibility, and included in the review, along with the reasons for exclusion at each stage (Mohamed Shaffril et al., 2021).

3.4. Data Coding and Analysis

To explore RQ1, bibliometric mapping techniques were utilized. The final dataset was exported from Scopus into VOSviewer 1.6.20, a freely available software tool for visualizing bibliometric networks (van Eck & Waltman, 2017). This software tool facilitated a comprehensive analysis of the citation data, identifying leading journals, sources, and authors in the discourse (Donthu et al., 2021).

To address the remaining research questions through a systematic review, all 20 selected papers were thoroughly read, and comprehensive summaries were created for each study. These summaries included information on the type of AI application, teaching content, educational level, research focus, objectives, impact on learning and teaching, pedagogical approach, methodology, and findings. The synthesis of findings involved a thematic analysis of the individual responses to the research questions, employing both inductive and deductive coding techniques (Celik et al., 2022; Fereday & Muir-Cochrane, 2006), as exemplified in Table 4. The emergent themes from these codes were used to compile the synthesis presented in the Results section.

Figure 2
PRISMA flow diagram

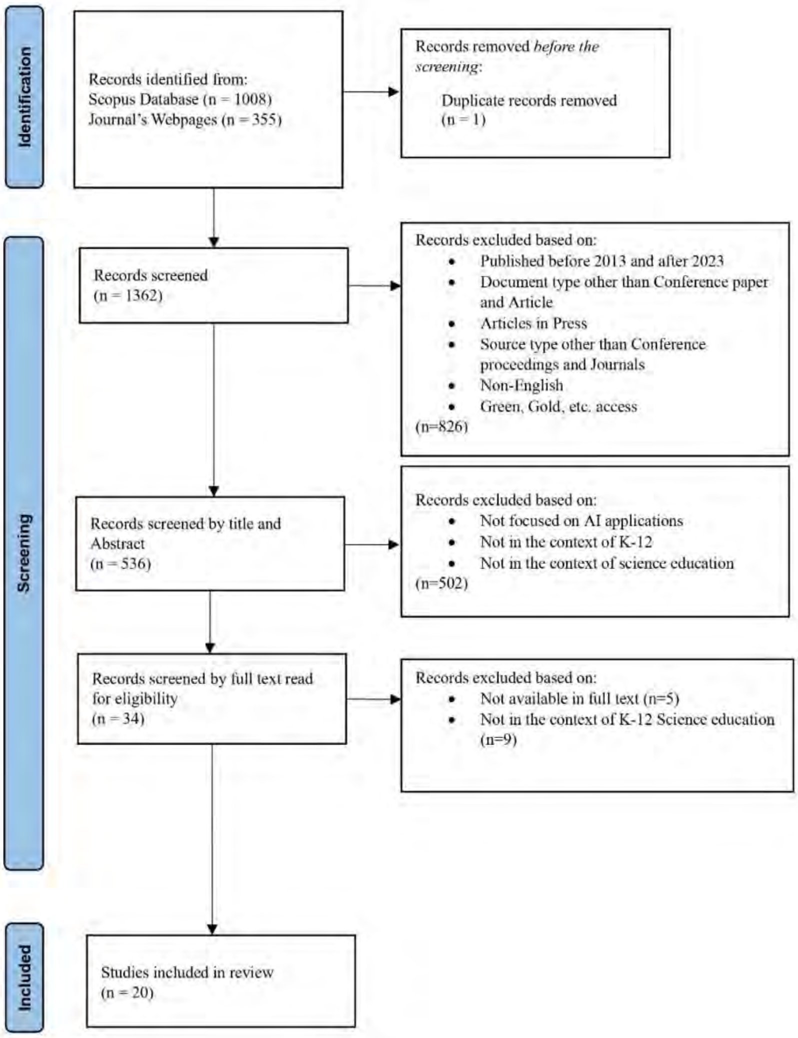


Table 4
Sample Coding process

Research Question	*Sample data*	*Code(s)*	*Theme(s)*
AI Application	"This study aims to develop a biology learning **chatbot** system to support grade 7 students' learning in biology classes" (Yen-Ting Lin & Yen-Ting Lin, 2023, p. 275).	Chatbot	Chatbot
Grade Levels	"The STEAM-graded teaching system in **primary school** is the focus of this exploration" (Shi & Rao, 2022, p. 3).	Primary school	Elementary School Grade
Methodology	"The above investigations are scoped to a **case study** of a single selective, independent UK school" (Denes, 2023, p. 2).	Case Study	Case study – Qualitative Research
Pedagogical Approach	"The core focus of this research is to address the needs of resource-constrained environments to teach scientific and technological concepts using a **learning-by-doing** approach" (Zahid Iqbal & Campbell, 2023, p. 2).	Learning by doing	Constructivism
Impact on Learning	"The overall **outcome confirms** that mobile robot programming is a valuable experience to **empower physics concepts"** (Ferrarelli & Iocchi, 2021, p. 821).	Concept enhancement	Students learning performance

4. Results and Discussion

4.1. Leading Journals, Publishers, and Countries on Pedagogical Incorporation of AI in K-12 Science Education

Given the rapid expansion of AI applications in education, identifying the most authoritative and impactful sources, including leading journals, papers, authors, and contributions within countries, is crucial for establishing a credible foundation for further research. This research question aims to enhance research credibility by grounding efforts in well-regarded literature through bibliometric mapping (Ellegaard & Wallin, 2015), identifying trends and gaps that can guide further exploration, collaboration, and facilitating the dissemination of evidence-based insights for educators and policymakers, ensuring informed and effective AI integration in educational contexts.

The bibliometric analysis identified three leading journals (see Table 5) that have significantly contributed to the field of AI incorporation in K-12 Science Education. The "International Journal of Science Education" (ISSN: 0950-0693), published by Routledge, has two publications with a total of 43 citations and holds a Q1 quartile ranking with an impact factor of 2.3 (2022). The "Journal of Science Education and Technology" (ISSN: 1059-0145), published by Springer Science and Business Media B.V., features one highly cited publication with 195 citations, a Q1 quartile ranking, and an impact factor of 4.2. "Education and Information Technologies" (ISSN: 1360-2357), also published by Springer, includes one influential paper cited 43 times, ranking in the Q1 quartile with a 2022 impact factor of 5.5.

Among the most influential publications (see Table 6), "Examining Science Education in ChatGPT: An Exploratory Study of Generative Artificial Intelligence" by Cooper (2023) stands out with 194 citations in the "Journal of Science Education and Technology." Another notable paper, "Chatbot application in a 5th grade Science course" by Deveci Topal et al. (2021), published in "Education and Information Technologies," has garnered 43 citations. Additionally, "Investigating the Impact of automated feedback on Students' scientific argumentation" by Zhu et al. (2017), published in the "International Journal of Science Education," has also received 43 citations.

The top five influential authors (see Table 7) were identified based on their publications and citation records. Zhai from the USA leads with two publications and 30 citations. Cooper from Australia has a single but highly cited publication with 194 citations. Authors from Turkey, including Deveci Topal, Dilek Eren, and Kolburan Geçer, each contributed one publication cited 43 times.

Figure 3 shows the distribution of K-12 AISE publications by the top 3 countries. The United States leads with five publications and 85 citations, indicating its substantial contribution to the field (Ahmad et al., 2024). Turkey and China each have two publications, with Turkey receiving 43 citations and China 21. This highlights the U.S. as a major player, while Turkey and China contribute notably to the research field.

Table 5
Top 3 influential Journals with K-12 AISE publications

Journal Name (ISSN)	*Publisher*	*No. of Publications*	*Total Citations*	*Quartile Ranking*	*Impact Factor (2022)*
International Journal of Science Education (9500693)	Routledge	2	43	Q1	2.3
Journal of Science Education and Technology (10590145)	Springer Science and Business Media B.V	1	195	Q1	4.2
Education and Information Technologies (13602357)	Springer	1	43	Q1	5.5

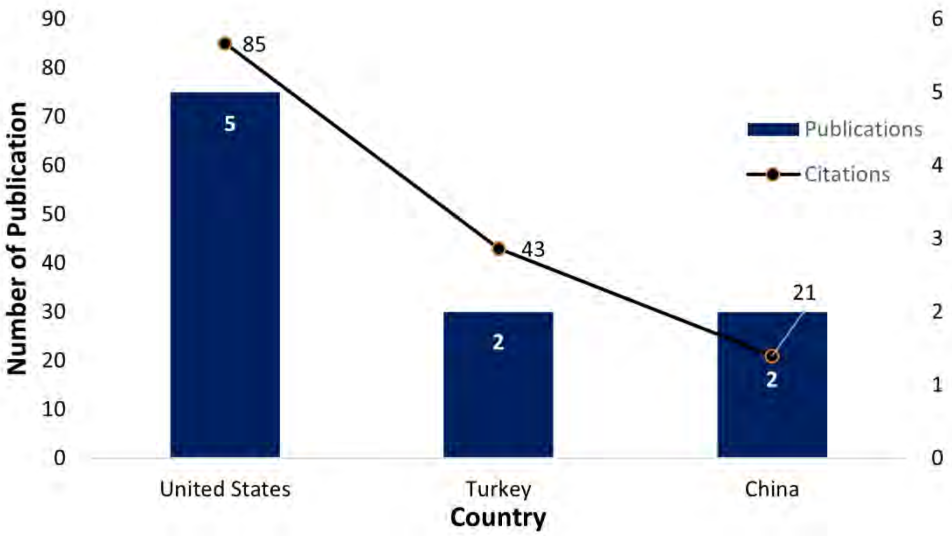
Table 6
Top 3 influential K-12 AISE publications

Title (Doi)	*Journal*	*Author(s) (Year)*	*Total Citations*
Examining Science Education in ChatGPT: An Exploratory Study of Generative Artificial Intelligence (10.1007/s10956-023-10039-y)	Journal of Science Education and Technology	Cooper (2023)	194
Chatbot Application in a 5th grade Science course (10.1007/s10639-021-10627-8)	Education and Information Technologies	Deveci Topal et al. (2021)	43
Investigating the Impact of Automated Feedback on Students' Scientific Argumentation (10.1080/09500693.2017.1347303)	International Journal of Science Education	Zhu et al. (2017)	43

Table 7
Top 5 influential authors in the field of K-12 AISE

Author (ID)	*No. of Publications*	*Country*	*Total Citations*
Zhai (57192683367)	2	USA	30
Cooper (55328948600)	1	Australia	194
Deveci Topal (55992931200)	1	Turkey	43
Dilek Eren (56010239800);	1	Turkey	43
Kolburan Geçer (26656715000)	1	Turkey	43

Figure 3
Top 3 Countries contributing to the field of K-12 AISE



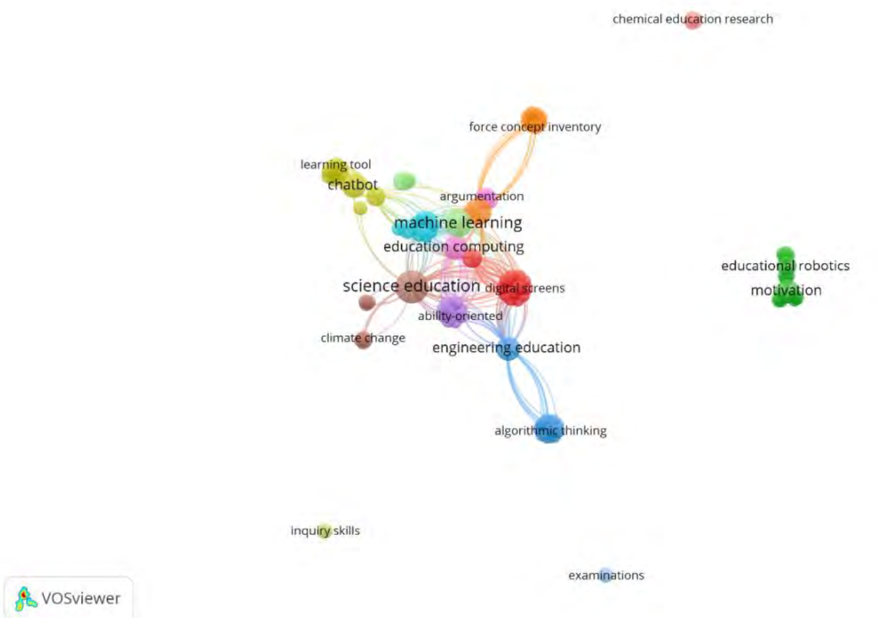
4.2. AI Technologies commonly utilized in K-12 Science Education

The reviewed literature indicates a diverse utilization of AI technologies in K-12 science education. The key AI technologies identified include robotics, chatbots, machine learning, automated scoring and feedback, and neural networks with fuzzy logic (see Table 8). These technologies are applied in various K-12 science educational contexts to enhance learning outcomes, support student engagement, and personalize learning experiences. To further illustrate these connections, an all-keyword co-occurrence network visualization using VOSviewer 1.6.20 was generated (Figure 4), with a minimum occurrence of one keyword. The network visualization revealed that the aforementioned technologies are closely linked to science education, with frequent use signaled by larger nodes and rare applications by smaller ones. Beyond the technologies detailed in this review, the visualization also showcased additional AI technologies employed in K-12 education that were not explicitly covered in the report.

Table 8
Overview of AI Technologies in K-12 Science Education from selected 20 literature

AI technology and application – use cases	*Key studies*	*Number of studies*
Robotics		
Hands-on Learning Cooperative Learning Inquiry-Based Learning Project-Based Learning	Mayub et al. (2023), Omari et al. (2023), Ferrarelli and Iocchi (2021), Fuhrmann (2021), Lu et al. (2021), Pedaste and Altin (2020), D'Amico et al. (2020)	7
Chatbot		
Inquiry-Based Learning Student Support	Cooper (2023), Yen-Ting Lin and Yen-Ting Lin (2023), Chuang et al. (2023), Deveci Topal (2021)	4
Machine Learning		
Predictive Analytics Personalized Learning Student- Supported Learning	Singh et al. (2023), Denes (2023), Haudek and Zhai (2023), Chang et al. (2023), Zahid Iqbal and Campbell (2023), Zhai et al. (2022)	6
Automated Scoring and Feedback		
Performance Analysis Automated Assessment Automated Feedback	Zhu et al. (2017)	1
Neural Networks and Fuzzy Logic		
Student -Supported Learning Predictive Analytics	Göktepe Körpeoğlu and Göktepe Yıldız (2024), Shi and Rao (2022)	2

Figure 4
Keyword Co-Occurrence Network of AI Technologies in K-12 Science Education



4.2.1. Robotics

Robotics involves designing, constructing, and using robots, often integrated with AI technologies, to perform tasks autonomously or interact intelligently with their environment (Cao et al., 2021). In this review study, robotics emerges as a prevalent AI technology in K-12 science education, with applications in hands-on learning, cooperative learning, inquiry-based learning, and project-based learning in line with the previous AI-Robots in Education [AIRE] studies (Bano et al., 2023; Chu et al., 2022; Yang & Zhang, 2019). Seven studies highlight the effectiveness of robotics in improving scientific literacy, motivation, and inquiry skills among students. For example, Mayub et al. (2023) investigated the impact of robotics experiments on junior high school students' scientific literacy, while Omari et al. (2023) examined how educational robots affect students' motivation and learning of thermodynamic concepts. These studies suggest that robotics can efficiently engage students in active learning and enhance their understanding of scientific concepts.

4.2.2. Chatbots

Chatbots are AI-driven programs that simulate human conversation (Adamopoulou & Moussiades, 2020; Khanna et al., 2015). Previous studies have demonstrated the educational efficacy of chatbots in offering immediate support, addressing inquiries, and enhancing learning experiences (Labadze et al., 2023; Pérez et al., 2020).

The present review study has pinpointed chatbots' applicability in inquiry-based learning and student support, backed by four studies demonstrating their effectiveness. Cooper (2023) explored the use of ChatGPT in science education, highlighting its potential to support students' inquiries. Further, Yen-Ting Lin and Yen-Ting Lin (2023) developed an educational chatbot system to enhance the performance of biology learning. These studies collectively advocate for chatbots as facilitators of personalized learning journeys, offering real-time support and feedback to students (Gill et al., 2024; Lee & Yeo, 2022). Consequently, they can foster heightened engagement and improved learning outcomes within science classrooms.

4.2.3. Machine learning

Machine learning, a subset of AI, involves training algorithms on large datasets to make predictions or decisions without explicit programming (Korkmaz & Correia, 2019; Shah et al., 2021). In education, its applicability has been explored for predictive analytics, which uses data, statistical algorithms, and ML techniques to forecast future outcomes based on historical data. This approach predicts student performance, identifies at-risk students, and tailors learning experiences to individual needs, enhancing educational outcomes (Kurni et al., 2023). The review identified six studies emphasizing various applications of ML, including personalized learning, predictive analytics, and student-supported learning. For instance, Singh et al. (2023) developed an educational software system using ML technology to assist visually impaired students in STEM subjects, demonstrating how ML can tailor educational content to individual needs. Further, Denes (2023) utilized ML to predict GCSE grades, while Chang (2023) applied it to predict students' STEM significant choices. These applications underscore ML's potential in creating adaptive learning environments in science classrooms that respond to the unique needs of each student, thereby improving educational outcomes.

4.2.4. Automated scoring and feedback

Automated scoring and feedback involve using AI technologies to assess student performance and provide immediate, constructive feedback (Hahn et al., 2021). For instance, the review identified a study by Zhu et al. (2017) that explored the impact of automated feedback on students' scientific argumentation skills, showing how AI can improve feedback quality by identifying areas of improvement in reasoning. The benefits of such automated systems include their ability to process large volumes of student work rapidly and provide detailed, consistent, and timely feedback, allowing students to correct misconceptions and reinforce learning in real-time (Liu et al., 2016). In addition to improving scientific argumentation, automated scoring and feedback systems in science education can be applied to assess complex tasks such as lab report evaluations, data analysis exercises, and simulations, where AI can instantly identify errors in experimental design, data interpretation, or hypothesis testing, offering students precise feedback that fosters a deeper understanding of scientific methods and concepts (Gonzalez et al., 2024).

4.2.5. Neural networks and fuzzy logic

The review underscored the utilization of advanced AI techniques, such as neural networks and fuzzy logic used for pattern recognition and decision-making processes (Göktepe Yıldız & Göktepe Körpeoğlu, 2024; Mehra et al., 2023). Notably, two studies showcased their application in predictive analytics and student-supported learning within K-12 science education. Göktepe Körpeoğlu and Göktepe Yıldız (2024) employed an adaptive neural-network-based fuzzy logic model to forecast students' STEM attitudes, unveiling these technologies' potential to anticipate student needs. Similarly, Shi and Rao (2022) developed a STEAM-graded teaching system using a backpropagation neural network model, demonstrating neural networks' role in providing adaptive learning environments.

4.3. Incorporation of AI in K-12 Science Education in terms of Grade Levels and Methodological Approaches

The distribution of reviewed studies by grade levels and methodological approaches is presented in Table 9. The majority of studies focused on high school settings (n=10, 50%), followed by middle school (n=8, 40%) and elementary school (n=2, 10%). While the prevalence of research in high school settings is notable (Triansyah et al., 2023), more studies are still needed to focus on elementary and middle school levels. Such studies would contribute to a more comprehensive understanding of educational practices and outcomes across all grade levels in science classrooms, ensuring that innovative AI technological approaches can be effectively tailored to meet the diverse needs of students at different stages of their science educational journey.

Among the methodological approaches employed, design and developmental research (Richey & Klein, 2014) emerged as the most prevalent, with eight studies adopting this methodology. Notably, this approach was particularly prominent in high school settings, with 4 out of 8 studies focusing on this educational level. For instance, Zahid Iqbal and Campbell (2023) developed an innovative AGILEST approach, utilizing ML agents to enhance kinesthetic learning in STEM education through real-time touchless hand interaction. Similarly, Lu (2021) contributed to this body of research by designing and implementing VR2E2C, a Virtual Reality Remote Education for Experimental Chemistry Systems, to address the need for safe and highly fault-tolerant experimental topics. Furthermore, within the experimental/quasi-experimental category (Mize & Manago, 2022), 4 out of 5 studies utilized a quasi-experimental design, which involved dividing participants into an experimental group, where AI technology (e.g., Educational Chatbot (Yen-Ting Lin & Yen-Ting Lin, 2023) was applied, and a control group without the intervention. Subsequently, pre-and post-test analyses were conducted to evaluate the impact of the intervention on the experimental group compared to the control group (Maciejewski, 2020). Additionally, four studies employed a mixed-method approach with an initial quantitative phase followed by qualitative (Ivankova et al., 2006), and two studies employed theoretical or descriptive research. Another study employed a case study research design. These findings underscore the diverse methodological approaches used to investigate AI incorporation in K-12 science education settings, highlighting the importance of considering various research methodologies to comprehensively understand educational practices and outcomes.

The review of methodological approaches highlights how AI integration varies across different educational stages, reflecting the specific needs, maturity, and complexities of the technologies used. The significant focus on high school settings underscores the demand for rigorous and innovative approaches in advanced science education. However, there is a clear need for more research at the elementary and middle school levels to ensure that AI integration is developmentally appropriate for students across all K-12 levels.

Table 9

Distribution of Reviewed Studies by Grade Levels and Methodological Approaches

Research Dimensions	*Number of Studies Reviewed across the Dimensions*	
Grade Levels		
Elementary School (Grades K-5)	$n = 2$	(Deveci Topal et al., 2021; Shi & Rao, 2022)
Middle School (Grades 6-8)	$n = 8$	(Cooper, 2023; D'Amico et al., 2020; Fuhrmann et al., 2021; Göktepe Körpeoğlu & Göktepe Yıldız, 2024; Haudek & Zhai, 2023; Omari et al., 2023a; Yen-Ting Lin & Yen-Ting Lin, 2023; Zhai et al., 2022)
High School (Grades 9-12)	$n = 10$	(Chang et al., 2023; Chuang et al., 2023; Denes, 2023; Ferrarelli & Iocchi, 2021; Lu et al., 2021; Mayub et al., 2023; Pedaste & Altin, 2020; Singh et al., 2023; Zahid Iqbal & Campbell, 2023; Zhu et al., 2017)
Methodological Approaches		
Theoretical or Descriptive Research	$n = 2$	(Chang et al., 2023; Cooper, 2023)
Design and Developmental Research	$n = 8$	(Chuang et al., 2023; Göktepe Körpeoğlu & Göktepe Yıldız, 2024; Haudek & Zhai, 2023; Lu et al., 2021; Shi & Rao, 2022; Singh et al., 2023; Zahid Iqbal & Campbell, 2023; Zhai et al., 2022)
Experimental/Quasi-experimental Research	$n = 5$	(D'Amico et al., 2020; Ferrarelli & Iocchi, 2021; Pedaste & Altin, 2020; Yen-Ting Lin & Yen-Ting Lin, 2023; Zhu et al., 2017)
Mixed Method Research	$n = 4$	(Deveci Topal et al., 2021; Fuhrmann et al., 2021; Mayub et al., 2023; Omari et al., 2023a)
Case Study Research	$n = 1$	(Denes, 2023)

While design and developmental research and quasi-experimental designs have been prominent in the studies reviewed, there is growing recognition of the value of qualitative and mixed-method approaches. Qualitative studies offer deep insights into AI integration's contextual, experiential, and subjective aspects (Wang et al., 2024), revealing how these technologies influence learning and teaching across various educational settings. The main advantage of qualitative approaches is their ability to provide rich, detailed narratives that capture the complexity of AI's impact, although they can be time-consuming and challenging to generalize. Mixed-method approaches, which blend qualitative and quantitative research, provide a more comprehensive understanding by measuring the effects of AI technologies and uncovering the underlying reasons and contextual factors that shape these outcomes (Creswell & Clark, 2018). This combination allows for breadth and depth in the analysis, offering a holistic view of AI's impact. However, mixed-method studies can be resource-intensive and require expertise and careful integration of qualitative and quantitative phases to avoid conflicting interpretations.

Therefore, there is an increasing need for more qualitative and mixed-method studies to gain a deeper understanding of AI's impact on education. This understanding will guide the development of more effective and contextually appropriate AI implementations. In conclusion, future research should emphasize a balanced methodological approach with a stronger focus on qualitative and mixed-method studies across all grade levels. Such an approach will enhance the evidence base and support the development of AI technologies responsive to the diverse needs of K-12 students, ensuring that AI integration in education is both contextually rich and broadly applicable.

4.4. Key Pedagogical Approaches for Incorporating AI in K-12 Science Classrooms

The review of studies highlights a diverse range of pedagogical approaches to incorporating AI technologies in K-12 science education (Table 10). Hands-on learning emerges prominently through robotics (Eguchi, 2017). For instance, Mayub et al. (2023) investigated how robotics experiments enhance scientific literacy among junior high school students, while Ferrarelli and Iocchi (2021) demonstrated the effectiveness of learning Newtonian physics through programming robot experiments, emphasizing their role in experiential learning and boosting student engagement (Benitti & Spolaôr, 2017). Additionally, the AGILEST approach by Zahid Iqbal and Campbell (2023) illustrates how machine learning agents and real-time touchless hand interaction facilitate active learning through learning by doing experiences, further enriching science education environments (Putu Krisna Dewi et al., 2023).

Table 10
Distribution of Reviewed Studies by Pedagogical Approaches

Pedagogical Approaches	*Number of Studies*	
Hands-on Learning/ Learning by Doing	$n = 4$	(Ferrarelli & Iocchi, 2021; Mayub et al., 2023; Omari et al., 2023a; Shi & Rao, 2022)
Inquiry-based Learning	$n = 2$	(Cooper, 2023; Pedaste & Altin, 2020)
Blended Learning	$n = 3$	(Deveci Topal et al., 2021; Lu et al., 2021; Yen-Ting Lin & Yen-Ting Lin, 2023)
Project-based Learning	$n = 1$	(Fuhrmann et al., 2021)
Cooperative Learning	$n = 1$	(D'Amico et al., 2020)
Feedback based Learning	$n = 1$	(Zhu et al., 2017)

Blended pedagogical strategies that integrate traditional instruction with AI technologies (Hrastinski, 2019) are evidenced by studies such as Yen-Ting Lin and Yen-Ting Lin (2023), who developed an educational chatbot system aimed at improving students' performance in biology, and Lu et al. (2021), who implemented intelligent virtual reality for experimental chemistry education. Moreover, Deveci Topal (2021) also utilized chatbots in a 5th-grade science course, further demonstrating the integration of AI technologies to support learning objectives in science classrooms. Furthermore, inquiry-based learning emerges as another prominent pedagogical approach (Pedaste et al., 2015), as highlighted by Pedaste and Altin (2020), whose study investigated the impact of inquiry-based education using robots on learners' inquiry skills and motivation. Similarly, Cooper (2023) explored science education with ChatGPT, emphasizing the role of generative artificial intelligence in fostering inquiry-based, student-centered learning experiences (Ali et al., 2023). Additionally, project-based learning and cooperative learning pedagogical approaches were exemplified by Fuhrmann (2021), who integrated computational thinking and robotics in middle school science inquiry, and D'Amico et al. (2020), who developed experiential learning systems with educational robotics to promote collaborative problem-solving skills. Finally, feedback-based learning strategies (Deeva et al., 2021), studied by Zhu et al. (2017) investigating automated feedback on students' scientific argumentation, underscore the importance of timely and constructive feedback in enhancing learning outcomes (Mirmotahari et al., 2019). Together, these studies illustrate the multifaceted applications of AI technologies across various pedagogical frameworks, highlighting their potential to transform and enrich science education practices across K-12 settings.

The identified pedagogical approaches offer promising avenues for integrating AI in K-12 science education. Hands-on learning and learning-by-doing approaches, especially robotics and machine learning, can significantly enhance student engagement and scientific literacy by providing experiential learning opportunities that align with real-world applications (Yannier et al., 2020). However, successful implementation requires addressing challenges such as resource availability and accessibility and teacher training and literacy in these technologies. Further, Inquiry-based learning and project-based learning, which promote critical thinking and problem-solving, could benefit from AI's ability to deliver personalized learning experiences and real-time feedback (Deák et al., 2021). To maximize their impact, ongoing research and pilot programs should evaluate these approaches' long-term effects on student outcomes and refine AI tools to support them better. Blended learning and cooperative learning strategies, which merge traditional and digital environments, offer flexibility and inclusivity, making them suitable for diverse classroom settings (Ramadevi et al., 2023). Ensuring seamless integration of AI within these strategies is crucial to enhance collaboration and interaction while maintaining pedagogical goals. Additionally, future implementations must consider equitable access to AI tools, particularly in under-resourced schools. Lastly, augmented by AI's automated feedback capabilities, the feedback-based learning approach promises to improve student performance with timely, tailored responses (Ponnusamy et al., 2021). Nonetheless, the effects of AI-generated feedback on student motivation and self-regulation need careful monitoring to prevent over-reliance on technology at the expense of teacher-student interaction.

In conclusion, the future implementation of these pedagogical approaches will require a balanced consideration of their advantages and disadvantages. While AI offers significant potential to optimize science education, it also presents challenges related to resource allocation, teacher readiness, and equity (Luan et al., 2020). Future research should prioritize a comprehensive understanding of these factors, ensuring that AI technologies are implemented in a way that is both effective and contextually appropriate for diverse K-12 educational settings.

4.5. Impact of AI Incorporation on Learning in K-12 Science Classrooms

The incorporation of AI in K-12 science classrooms has significantly positively impacted students' learning performance and skills across the reviewed studies (Table 11). Robotics, a prevalent AI technology (Kálózi-Szabó et al., 2022), has been shown to enhance scientific literacy, motivation, and inquiry skills. For example, Mayub et al. (2023) reported that robotics experiments significantly motivated students to learn science, with an average motivation score of 4.02, indicating a "motivated" category. The experiments also increased students' scientific literacy and received positive responses from teachers, with average scores of 3.99 and 3.98, respectively, falling into the "good" category. Similarly, Omari et al. (2023) found that educational robotics significantly improved students' understanding of thermodynamic concepts and motivation, with the experimental group achieving higher post-test scores (mean = 13.27) and motivation ratings (mean = 4.68) compared to the control group (mean post-test score = 8.43, mean motivation rating = 3.33). Further, chatbots have also proven beneficial in academic settings (Mutovkina, 2021). For instance, Yen-Ting Lin and Yen-Ting Lin (2023) found that their biology learning chatbot significantly improved students' learning outcomes, particularly for those with limited previous knowledge, with the experimental group showing a higher adjusted mean score (71.07) and a large effect size of 0.301, while Deveci Topal (2021) highlighted the chatbot's positive impact on students' online learning experiences despite no significant difference in academic achievement between the experimental and control groups. Additionally, automated scoring and feedback systems (Wilson et al., 2021) have been shown to improve specific skills, such as scientific argumentation. Zhu et al. (2017) demonstrated that students' argumentation scores significantly improved after receiving automated feedback, with each revision associated with higher final scores. On average, students revised 2.08 argumentation blocks, with revisions leading to higher final scores and each round of revision taking an average of 11.79 seconds.

The methods employed in these studies to observe the impact of AI on students' learning performance and skills in K-12 science education were diverse, including quantitative and mixed-method approaches. Many studies utilized experimental designs (n=4) with pre-test and post-test measures. For instance, Ferrarelli and Iocchi (2021) used quantitative experimental methods with Force Concept Inventory [FCI] pre-test and post-test to measure students' understanding of Newtonian physics after engaging with robotics, showing an improvement from 10–29% to 30–49% in students' understanding of Newtonian physics. Mixed-method approaches were also evident (n=4), as seen in Fuhrmann (2021), who combined pre- and post-pseudocode tasks with students' post-interviews to evaluate the enhancement of computational thinking skills through robotics, finding that 64% of students showed significant improvement in computational thinking skills. Additionally, the study by Zhu et al. (2017) employed quantitative methods using log data to track students' initial and final scores, analyzing the impact of automated scoring and feedback on scientific argumentation skills. This diversity in methodological approaches highlights the robust and multifaceted nature of research in this field, ensuring a thorough investigation of the educational impacts of AI technologies.

5. Implications for Stakeholders

The integration of Artificial Intelligence technologies in K-12 science education, as evidenced by the reviewed studies, offers promising opportunities to enhance learning outcomes, student engagement, and personalized education. However, successfully implementing these technologies requires carefully considering several key implications for educators, policymakers, and researchers. One of the primary implications is the need for comprehensive professional development programs for educators (Nazaretsky et al., 2022). Educators must have the knowledge and skills to effectively integrate AI tools and technologies into their teaching practices (Lee & Perret, 2022). This includes understanding the functionalities of AI technologies like robotics, chatbots, and machine learning and developing pedagogical strategies that leverage these tools to foster critical thinking, problem-solving, and scientific inquiry. Continuous professional development will ensure that educators remain updated with the latest advancements and can confidently incorporate AI into their curricula (Kim, 2024). Further, Policymakers play a crucial role in facilitating the integration of AI in education by investing in the necessary infrastructure and resources (Schiff, 2022). Schools need access to high-quality hardware and software, reliable internet connectivity, and technical support to implement AI technologies effectively (Gil-Flores et al., 2017).

Table 11

A summary of review studies documenting observations on the impact of students' learning performance and skill.

Author(s) (Year)	*AI Technology*	*Major Research Objective*	*Method*	*Observation about the impact on students' learning performances and skills*
Mayub et al. (2023)	Robotics	To evaluate whether robotics experiments can enhance students' scientific literacy, motivate them to learn science, and improve teachers' responses to these experiments.	Mixed method- questionnaires, observations, and interviews	Results showed that Robotics experiments were found to motivate students to learn science, increase scientific literacy, and receive positive teacher responses.
Omari et al. (2023)	Robotics	To determine the impact of educational robotics on students' motivation and learning of thermodynamic concepts.	Mixed method- Experimental study; pre-test and post-test and Survey Questionnaire	The study found that educational robotics stimulates student motivation and learning better than traditional laboratory equipment.
Yen-Ting Lin and Yen-Ting Lin (2023)	Chatbot	To develop and evaluate the impact of a biology learning chatbot on students' learning achievement in biology.	Quantitative method - experimental study; pre-test and post-test	The proposed Chatbot system significantly enhanced students' learning outcomes, particularly benefiting those with low prior knowledge.
Ferrarelli and Iocchi (2021)	Robotics	To assess the impact of programming a mobile robot for physics experiments on understanding concepts of Newtonian physics.	Quantitative method - experimental study; pre-test and post-test Force Concept Inventory (FCI)	The findings showed that students who programmed a robot for physics experiments significantly improved their understanding of Newtonian physics concepts compared to those who received conventional curricular physics lessons.
Fuhrmann et al. (2021)	Robotics	To assess how using robotics for science experimentation enhances computational thinking (CT) skills.	Mixed method- Experimental study; pre- and post-pseudocode tasks, and post-interviews	Students showed an improved understanding of computational thinking (CT) by conducting a science experiment using the Liquid Handling Robot (LHR).

Table 11 continued

Author(s) (Year)	*AI Technology*	*Major Research Objective*	*Method*	*Observation about the impact on students' learning performances and skills*
Deveci Topal et al. (2021)	Chatbot	To assess the impact of chatbots on students' academic success and their opinions regarding chatbots.	Mixed method- Quasi-experimental study; pre-test and post-test and semi-structured interviews	The study found that although academic achievement did not differ significantly between the experimental and control groups, the chatbot application positively enhanced the online learning experience for experimental group students. Additionally, students found the chatbot beneficial and expressed a keen interest in utilizing it for other courses, highlighting its support for learning beyond traditional classroom settings.
Pedaste and Altin (2020)	Robotics	To evaluate the impact of robot-based physics learning on inquiry skills, content knowledge, and motivation.	Quantitative method - experimental study; pre-test and post-test	Findings showed that inquiry-based activities using robots enhance inquiry skills and subject knowledge, but they are not more effective than traditional teaching methods, particularly without sufficient guidance. Additionally, while robots initially increase student motivation, this effect diminishes over time, particularly for students with prior experience using them in learning contexts.
D'Amico et al. (2020)	Robotics	To investigate how educational robotics impact learners' understanding of physics and geography and their motivation.	Quantitative method – Quasi-experimental study; pre-test and post-test	The findings demonstrated that the experimental group achieved superior learning outcomes compared to the control groups.
Zhu et al. (2017)	Automated Scoring and Feedback	To Investigate the role of automated scoring and feedback in improving students' scientific argumentation skills.	Quantitative method – Log data; initial and final scores	The study found a significant improvement in argumentation scores following revisions based on the provided feedback.

Additionally, there should be a focus on ensuring equitable access to these resources across different schools and districts, particularly in underserved and rural areas (Berendt et al., 2020). This will help bridge the digital divide and allow all students to benefit from AI-enhanced learning environments (Ajani et al., 2024; Mnguni, 2023).

Along with the beneficial aspects, using AI in education raises critical ethical considerations, particularly regarding data privacy and security (Schiff et al., 2021). AI systems often collect and analyze student data to provide personalized learning experiences. Therefore, it is essential to establish robust data protection policies that safeguard students' privacy and comply with legal and ethical standards. Policymakers and educational institutions must work together to create guidelines, regulations, and national-level or international-level responsible AISE policy frameworks to ensure the responsible use of AI technologies in science education (Dennehy et al., 2023; Nguyen et al., 2023). Furthermore, Integrating AI into K-12 science education also necessitates updates to the curriculum to include AI literacy (Casal-Otero et al., 2023). Students should be introduced to fundamental AI concepts, its applications, and its impact on society. This will prepare them for future academic and professional pursuits and empower them to evaluate and engage with AI technologies critically. Additionally, advancing AI incorporation in science education requires interdisciplinary collaboration among educators, researchers, technologists, and policymakers. Such collaboration can drive innovation, ensure the pedagogical soundness of AI technologies, and address practical challenges in implementation. In conclusion, these implications provide a roadmap for stakeholders to ensure that AI technologies are effectively and responsibly integrated into K-12 science educational settings, ultimately enhancing the educational experiences and outcomes for all students.

6. Conclusion

This systematic literature review and bibliometric analysis comprehensively explored the pedagogical incorporation of AI technologies in K-12 science education from 2013 to 2023. The identified leading journals, impactful papers, influential authors, and countries' contributions highlight a robust discourse aimed at enhancing learning outcomes in science education through innovative AI applications such as robotics, chatbots, machine learning, and automated feedback systems (Alam, 2022; Timms, 2016). Further, the diverse methodological approaches employed across grade levels highlight AI's adaptability and potential to address different educational contexts (Chen et al., 2020). Notably, the reviewed studies consistently demonstrate AI's positive impact on student engagement and learning performance in science classrooms (Heeg & Avraamidou, 2023). Additionally, pedagogical strategies such as hands-on learning, blended approaches, inquiry-based methods, and feedback systems have proven effective across grade levels with AI incorporation (Al Darayseh, 2023).

While this review provides valuable insights, it also acknowledges the following limitations. Firstly, the scope was confined to studies indexed in the Scopus database, potentially limiting relevant research published in other databases. Secondly, focusing on English-language publications may miss significant findings from non-English sources, limiting the global perspective. Thirdly, the review included only studies available in full text, which may have excluded potentially relevant research accessible only in abstract form or behind paywalls. Additionally, the literature collected by the review, including articles and conference proceedings, will be available only until 2023, potentially missing recent advancements in the field. Future research should address these limitations by expanding the scope to include other relevant databases and non-English studies to provide a more comprehensive understanding of AI's role in K-12 science education. Longitudinal studies are essential to assess the long-term impacts of AI on student learning outcomes and engagement (White & Arzi, 2005). Furthermore, exploring the ethical implications and challenges of AI integration in educational settings will be crucial to ensuring these technologies' responsible and equitable use (Akgun & Greenhow, 2022; Mhlanga, 2023). Further, the review underscores the importance of qualitative and mixed-method research in understanding the intricate impacts of AI integration. With more profound insights into students' and teachers' experiences, perceptions, contextual factors, and challenges with AI technologies, qualitative and mixed-method studies can inform the development of more user-friendly and contextually relevant AI applications in education (Baškarada & Koronios, 2018; Rodrigues et al., 2024). Moreover, the qualitative and mixed method investigations and broader representation across grade levels suggest further avenues for future inquiry into AI's incorporation into science education. These steps will collectively advance knowledge and inform policy decisions in the evolving field of AI in education.

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